VOL. 12 NO. 2 APRIL, 1955

BRITISH JOURNAL OF INDUSTRIAL MEDICINE

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CONTENTS

	PAGE
Mortality from Lung Cancer in Asbestos Workers. RICHARD DOLL	81
Primary Lung Cancer in South Wales Coal-workers with Pneumoconiosis. W. R. L. JAMES	87
Pulmonary Fibrosis in Non-ferrous Foundry Workers. H. E. HARDING and A. I. G. MCLAUGHLIN	92
Leptospiral Serology in Scottish Coal-miners. R. S. F. ADAM and P. N. EDMUNDS	100
Diurnal Variation in Mental Performance. BO BJERNER, ÅKE HOLM, and ÅKE SWENSSON	103
Physiological Observations on Men Working in Supposedly Limiting Environments in a West African Gold-mine. W. S. S. LADELL	111
The Influence of Inspired Air Temperature on Tolerance to Work in the Heat. A. R. LIND	126
Investigations into the Effects of Exposure to Trichlorethylene in Mechanical Engineering. E. GRANDJEAN, R. MÜNCHINGER, V. TURRIAN, P. A. HAAS, H.-K. KNOEPFEL, and H. ROSENMUND	131
Conference of the British Occupational Hygiene Society on Radiation Hazards in Industry :	
The Health of Workers Exposed to Ionizing Radiations. A. S. MCLEAN	143
Radiation Safety at an Atomic Energy Factory. D. R. R. FAIR	147
Protection against *X* rays and Gamma rays in the Industrial Field. W. BINKS	153
Safety Criteria in Atomic Energy. F. R. FARMER	163
Miscellanea :	
Occupational Dermatitis Caused by Ethylene Oxide. A. ROYCE and W. K. S. MOORE	169
Blood Examinations in Industry : A Comparison of Blood Cell Counts from Ear Lobe and Thumb Pulp. A. BUTTERWORTH and N. GOODMAN	172
Raynaud's Phenomenon. ANDREW MEIKLEJOHN	174
First Ordinary Scientific Meeting of the British Occupational Hygiene Society	177
Obituary : Cecil Gordon Roberts	179
Books Received	180

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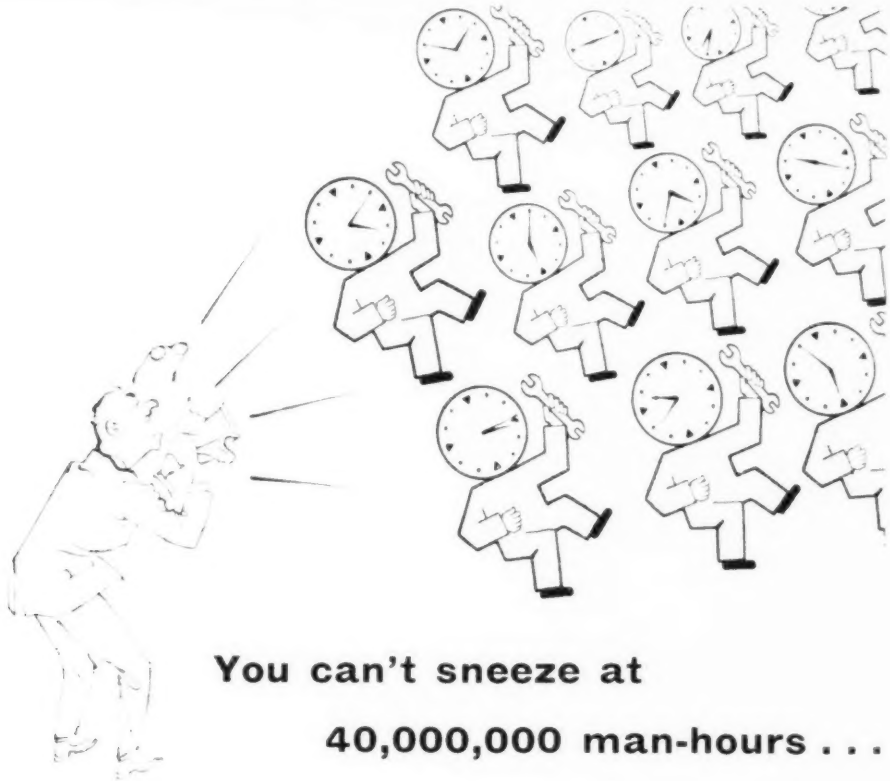

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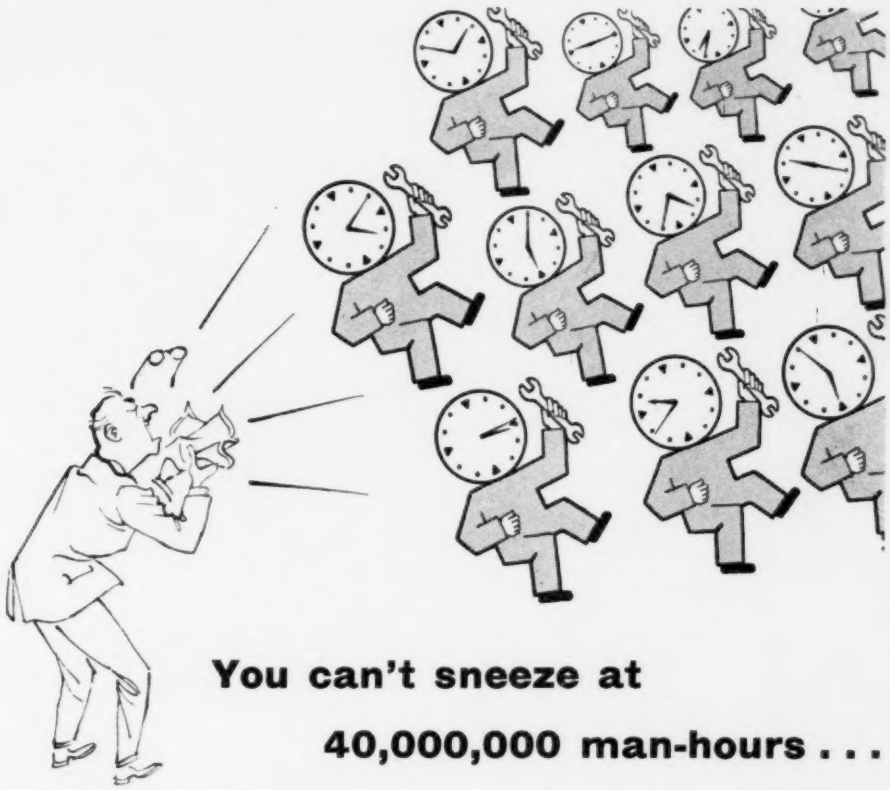

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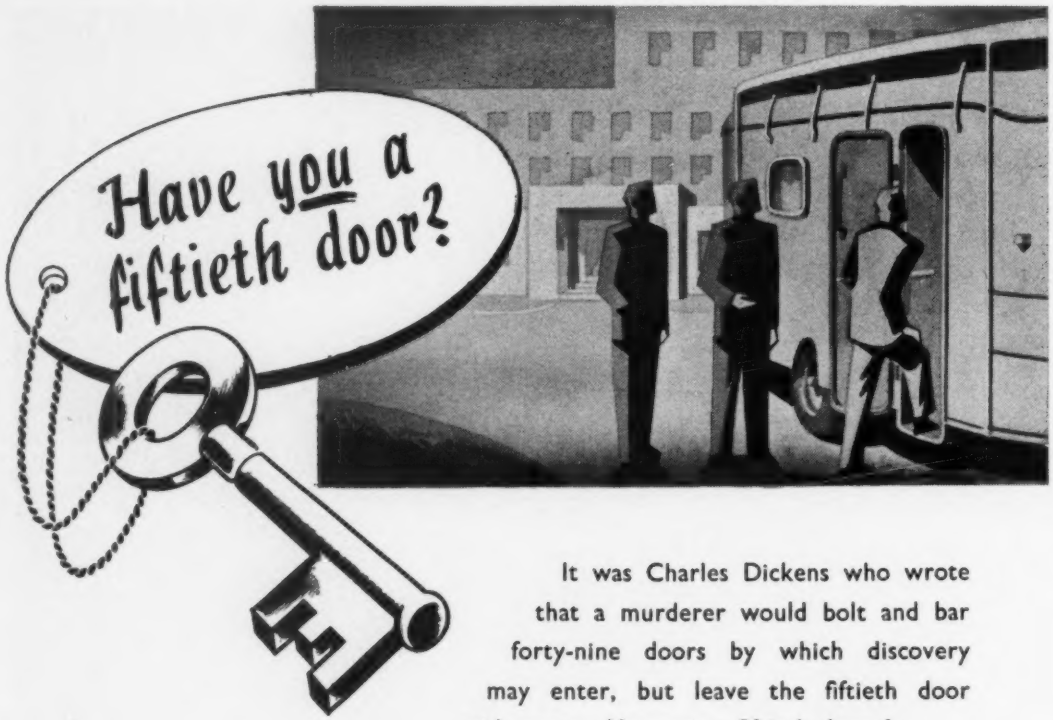

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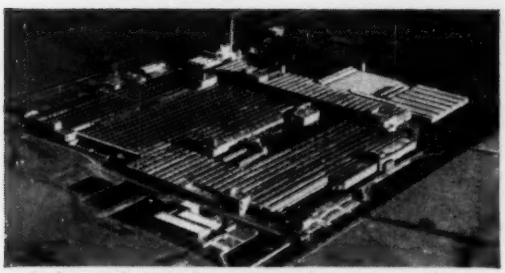

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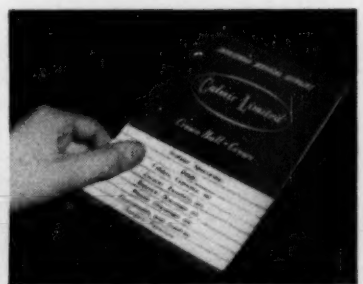

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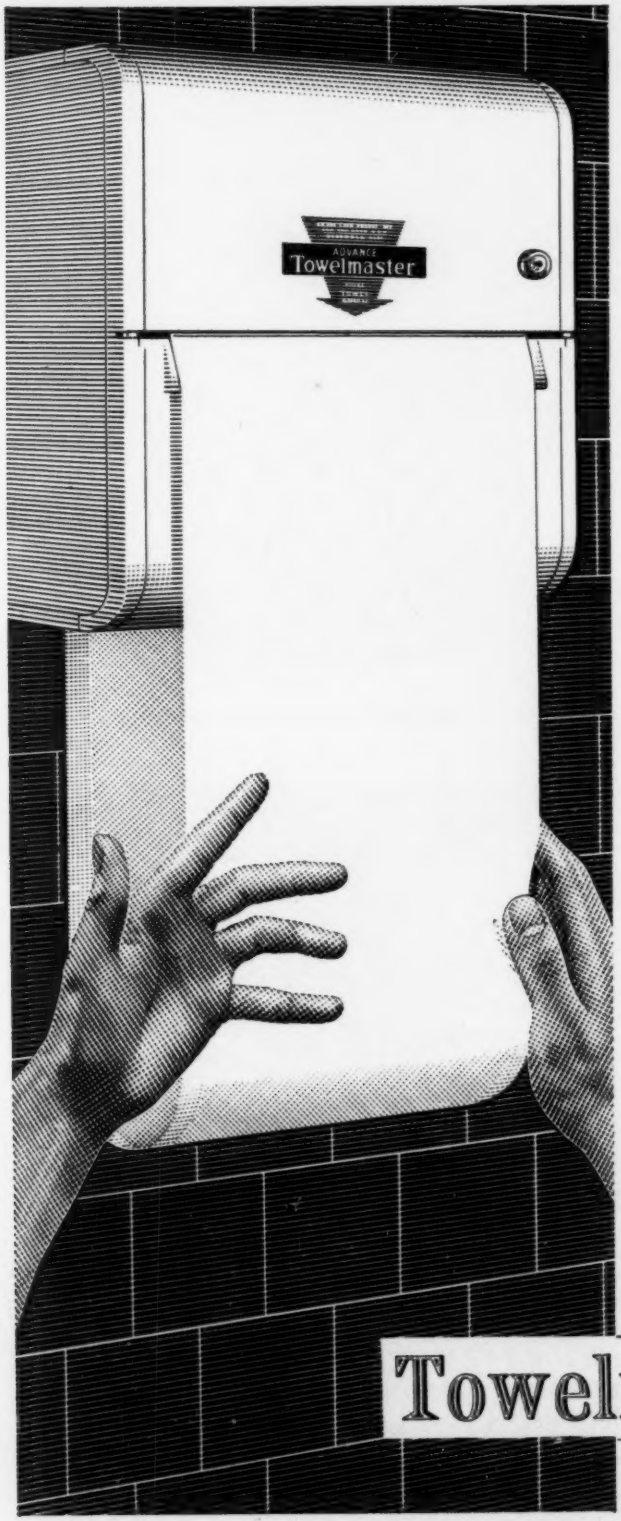

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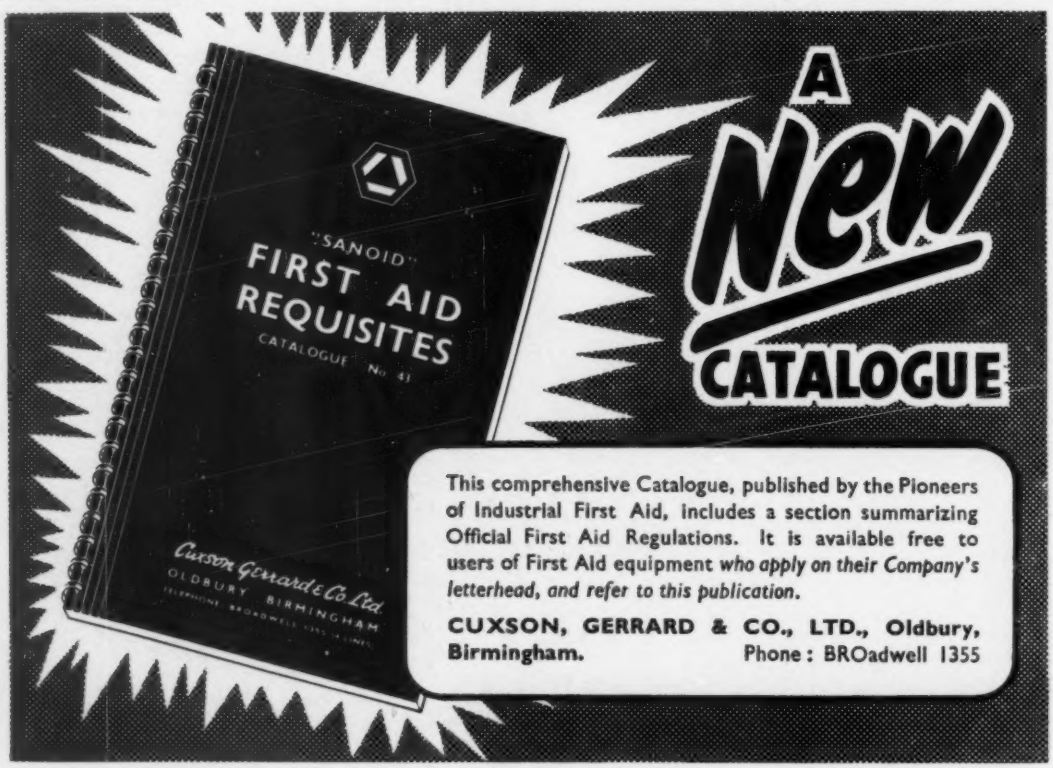
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Brit. J. industr. Med., 1955, **12**, 81.

MORTALITY FROM LUNG CANCER IN ASBESTOS WORKERS

BY

RICHARD DOLL

From the Statistical Research Unit, Medical Research Council, London

(RECEIVED FOR PUBLICATION AUGUST 10, 1954.)

Sixty-one cases of lung cancer have been recorded in persons with asbestosis (Boemke, 1953 ; Hueper, 1952) since Lynch and Smith (1935) reported the first case. In view of the infrequency of asbestosis, this large number of cases suggests—but does not prove—that lung cancer is an occupational hazard of asbestos workers. The strongest evidence that it may be a hazard has been produced by Merewether and by Gloyne. Merewether (1949) found that lung cancer was reported at necropsy in 13·2% of cases of asbestosis (31 out of 235) but in only 1·3% of cases of silicosis (91 out of 6,884) and Gloyne (1951), on personal examination, found lung cancer in 14·1% of necropsies on subjects with asbestosis (17 out of 121) against 6·9% in silicotics (55 out of 796). Neither author gave full details of the sex composition of the groups examined, but since women form a higher proportion of asbestos workers than of persons employed in occupations liable to give rise to silicosis (coal-miners, stonemasons, pottery workers, foundrymen, metal grinders) and since lung cancer is less common among women, the differences in the proportions of cancer cases cannot be accounted for by differences in sex distribution. In fact the proportions which are more properly comparable with the findings in silicotic subjects are the proportions of lung cancer found among men with asbestosis, 17·2% in Merewether's series and 19·6% in Gloyne's.

Animal experiments are inconclusive. A positive result was reported by Nordmann and Sorge (1941) who found that of 10 mice which had been exposed to asbestos dust and survived for 240 days, two developed lung carcinoma. Smith (1952), however, considers that one of the " carcinomas " was, in fact, an example of squamous metaplasia and that the other, an adenocarcinoma, may have developed spontaneously from the common mouse adenoma. A negative result has been reported by Vorwald and Karr (1938). The majority of workers (cited by Hueper, 1952) consider that a causal relationship between asbestosis and lung cancer is either proved or is highly probable and the reality of the relationship was agreed at the recent International Symposium on the Endemiology of Lung Cancer (Council of the International Organizations of Medical Sciences, 1953). A minority, however, remains sceptical (Cartier, 1952 ; Warren, 1948), and, according to Hueper (1952), Lanza and Vorwald, so that it was thought desirable to undertake a fresh investigation.

Necropsy Data

Since 1935, records have been collected of all the coroners' necropsies on persons known to have been employed at a large asbestos works.* Pathological diagnoses in 105 consecutive cases are summarized in Table 1. Details of the cases in which lung cancer was found are shown in Table 2. During the first half of the period eight deaths occurred in which lung cancer was found in association with asbestosis, while in the second half of the period there were seven such cases and a further three in which lung cancer was found without asbestosis. The number of asbestos workers employed at the works increased steadily from 1914.

TABLE 1

CAUSES OF DEATH DIAGNOSED AT NECROPSY AMONG PERSONS EMPLOYED AT AN ASBESTOS WORKS (1933–52)

Cause of Death	Asbestosis Present	Asbestosis Absent	All Cases
" Heart failure "	34	11	45
Pulmonary tuberculosis ..	12	9	21
Lung cancer	15	3	18
Other diseases of the respiratory system	10	4	14
Other diseases	4	3	7
All causes	75	30	105

* Necropsies on asbestos workers are ordered by the coroner when in his opinion, there may be a question of asbestosis being a contributory cause of death.

TABLE 2

OCCUPATIONAL HISTORY AND NECROPSY DATA OF ASBESTOS WORKERS WITH PRIMARY LUNG CANCER

Year of Death	Sex and Age	Occupation	Period of Exposure	Years of Exposure	Years of Exposure before Jan. 1, 1933	Years from First Exposure to Death	Years from Last Exposure to Death	Pathological Report	
								Asbestosis	Histological Type of Primary Lung Cancer
1935	M. 62	Weaver	1919–32	13	13	16	3	Present	"Carcinoma"
1935	M. 54	Weaver	1909–32	23	23	26	3	,,	Epithelial carcinoma
1936	M. 65	Fiberizer	1913–36	23	19	23	Less than 1	,,	Endothelioma of pleura
1938	M. 47	Weaver	1910–12 1920–37	19	14	28	1	,,	"Carcinoma"
1939	M. 49	Disintegrater	1910–14 1919–39	24	17	29	Less than 1	,,	"Carcinoma"
1940	M. 52	Disintegrater	1911–15 1919–21 1923–39	22	15	29	Less than 1	,,	"Carcinoma"
1941	M. 52	Weaver	1913–19 1924–38	20	14	28	3	,,	Oat-celled carcinoma
1942	M. 59	Bag carrier	1913–41	28	19	29	1	,,	Oat-celled carcinoma
1948	M. 59	Weaver	1912–14 1918–48	32	16	36	Less than 1	,,	Anaplastic carcinoma
1948	M. 53	Weaver	1922–35	13	10	26	13	,,	"Carcinoma"
1948	M. 48	Spinner	1922–48	26	10	26	Less than 1	,,	"Carcinoma"
1948	M. 65	Maintenance man	1919–48	29	13	29	Less than 1	,,*	Oat-celled carcinoma
1950	F. 51	Spinner	1915–42	27	17	35	8	,,	"Carcinoma"
1951	M. 74	Fiberizer	1917–43	26	15	34	8	,,	Adenocarcinoma
1951	M. 60	Weaver	1919–25 1929–50	27	9	32	1	,,	"Carcinoma"
1944	M. 36	Weaver	1942–44	2	0	2	Less than 1	Absent	Oat-celled carcinoma
1951	M. 43	Fiberizer	1939–48	9	0	12	3	,,	Anaplastic carcinoma
1952	M. 51	Weaver	1941 (3/12) 1945–52	7	0	11	Less than 1	,,	"Carcinoma"

*Also pulmonary tuberculosis.

and a great increase in the number of lung cancer deaths was also recorded among the whole population of England and Wales over the same period. It might, therefore, have been anticipated that a larger number of cases in which the two conditions were associated would have been found in the last 10 years. National regulations for the control of asbestos dust were, however, introduced in 1931 (Asbestos Industry Regulations, 1931) and the precautions taken to prevent dust dissemination in the works had become effective by the end of the following year. All the subjects in whom the two diseases were found together had been employed for at least nine years under the old conditions, and although 11 of the 15 men and women died within 30 years of their first exposure, the association of the two conditions has not yet been found in any person taken into employment during the last 31 years (1923–53). It is, therefore, possible that the reason more cases were not found in the second half of the period is that reduced exposure to dust has already begun to lessen the incidence and severity of asbestosis.

Method of Estimation of Risk

Although the necropsy data shown in Tables 1 and 2 suggest (1) that some groups of asbestos workers have suffered an increased risk of lung cancer, and (2) that the risk may now have decreased, it is not possible to be certain of either of these propositions without a more detailed knowledge of the whole mortality experience of the workers. The first proposition has, therefore, been tested by comparing the mortality experienced by that section of the male employees of the works referred to above, who had worked for at least 20 years in "scheduled areas"*, with the mortality recorded for all men in England and Wales; and the second proposition by comparing the incidence of lung cancer among men employed for different periods under the pre-1933 conditions. The investigation was limited to the small group of men who had been employed for at least 20 years, since the labour involved in searching out the individual records of

* By "scheduled areas" is meant those areas where processes were carried on which were scheduled under the Asbestos Industry Regulations of 1931 as being dusty.

men employed for shorter periods would be disproportionately great and, so far as was known from Table 2, would be comparatively unrewarding.

The date of birth, date of completing 20 years' work in the " scheduled areas ", and, where applicable, date of ceasing employment and date and cause of death were obtained, for each man, from the records of the firm's Personnel Officer. Full details were, in most instances, already available for the men who had ceased employment as well as for the greater number who continued to be employed, since some of those who had left were registered as having asbestosis and the attention of the firm had been drawn to the death of others, in view of the possibility of the cause of death being industrial in origin. All the remaining men were successfully traced and the relevant details obtained. This was not difficult since, by limiting the study to men who had been employed in one place for 20 years, few were found to have changed their job or to have moved out of the region.

From the data the numbers of men alive in each five-year age group were counted separately for each of the years from 1922 (the first in which a man was recorded as having had 20 years' service) to 1953. A man who had completed the 20 years before the beginning of a year and who was alive at the end of it was counted, for that year, as one unit ; a man who completed the period before the beginning of a year but who died during it, and a man who completed the period during a year and who survived to the end of it, were each counted, for that year, as half a unit ; the one man who died the same year as he completed his 20-year period was counted as a quarter of a unit.

The causes of death were recorded as they were given on the death certificate or, when available, as they were finally determined by necropsy. The causes were classified in five categories (see Table 4), and the numbers in each category were then compared with those which might have been expected to occur by multiplying the numbers of men alive in each five-year age group by the corresponding mortality rates for men in England and Wales over the same period. Because of the small numbers, however, the populations were not considered separately for each year, but were added together to form five groups living in the periods 1922–33, 1934–38, 1939–43, 1944–48, and 1949–53, and the mortality rates used for each group were those for the years 1931, 1936, 1941, 1946, and 1951. The rates for 1931 were used for the period 1922–33, rather than those for the mid-years, since disproportionately few men were under observation during the early part of the period. As an example of the method, the mortality rate for all neoplasms other than lung cancer among men in England and Wales aged 55 to 59 in 1951 was 2·778 per 1,000. The numbers of years lived in this age group in the five years 1949–53 were respectively 15 years, 15 years, 17½ years, 19 years, and 19 years. The number of deaths expected in the period was, therefore, estimated to be $(15 + 15 + 17\frac{1}{2} + 19 + 19) \times 2{\cdot}778/1{,}000 = 0{\cdot}238$. The total number of deaths expected from each category of diseases was obtained by adding the numbers thus calculated for each age group for each of the five periods.

The great majority of the men lived and, when they died, died in the town in which the works was situated, so that it would have been preferable to have based the calculation of the expected deaths on the death rates observed in that town rather than on the rates for all England and Wales. These, however, were not known in sufficient detail. Little error in the expected number of deaths from lung cancer is likely to have been introduced on this account since, according to Stocks (1952), the age-adjusted death rate for lung cancer among men in the town concerned was 96% of the rate for England and Wales. Stocks's figure was calculated only for the period 1946–49, but the proportion is unlikely to have varied greatly over the longer period of the investigation. The expected number of deaths from all causes is, however, likely to be somewhat underestimated since the age-adjusted death rate from all causes for the town is about 25% higher than the England and Wales rate (*i.e.* the excess was 22% in 1950, 28% in 1951, and 22% in 1952).

Results

The number of men studied was 113 ; the numbers of man-years lived in each of the five periods in each age group are shown in Table 3. The total number of deaths from all causes and the number of deaths observed in each of the five disease categories, together with the expected number of deaths, are shown in Table 4. From Table 4 it appears that the men who had been exposed to asbestos dust suffered

TABLE 3

NUMBER OF MAN-YEARS LIVED BY MEN WITH 20 OR MORE YEARS OF WORK IN A "SCHEDULED AREA"

Age (years)	Period					All Periods
	1922–33	1934–38	1939–43	1944–48	1949–53	
30–	0	0·5	1·5	0	0	2
35–	4·5	2	11	17·5	9	44
40–	9·5	16	33·5	48	55	162
45–	9·5	19·5	50	78·5	84	241·5
50–	6·5	25·5	39·5	85	96·5	253
55–	12	6	30	52	85·5	185·5
60–	15	3	5·25	25·5	36	84·75
65–	1	13·5	3	10	21·5	49
70–	0	2	9	3	3·5	17·5
75–79	0	0	1	1·5	0·5	3
All ages	58	88	183·75	321	391·5	1042·25

TABLE 4

CAUSES OF DEATH AMONG MALE ASBESTOS WORKERS COMPARED WITH MORTALITY EXPERIENCE OF ALL MEN IN ENGLAND AND WALES

Cause of Death	No. of Deaths		Test of Significance of Difference between Observed and Expected (Value of P)
	No. Observed	Expected on England and Wales Rates	
Lung cancer* :			
with mention of asbestosis..	11	—	<0·000001
without mention of asbestosis	0	0·8	
Other respiratory diseases (including pulmonary tuberculosis) and cardiovascular diseases :			
with mention of asbestosis ..	14	—	<0·001
without mention of asbestosis	6	7·6	
Neoplasms other than lung cancer	4	2·3	>0·1
All other diseases†	4	4·7	
All causes	39	15·4	<0·000001

* Including one case with pulmonary tuberculosis.

†Including two cases (benign stricture of oesophagus and septicaemia) in which asbestosis was present but was not thought to have been a contributory cause of death.

an increased mortality from lung cancer, other respiratory diseases and cardiovascular diseases, in association with asbestosis, but that their mortality from other diseases was close to that expected.

Four explanations of the findings are possible : (1) that all the men who had died of lung cancer were recorded because of interest in the condition, but that some of the records of other men dying of other diseases or still alive were omitted, with consequent underestimation of the expected number of deaths ; (2) that lung cancer was incorrectly and excessively diagnosed among the asbestos workers ; (3) that lung cancer was insufficiently diagnosed among the general population of England and Wales ; or (4) that the asbestos workers studied suffered an excess mortality from lung cancer.

It certainly cannot be claimed that the records of the Personnel Office were necessarily complete, but they were believed to be complete and no deficiency on this score would account for the total excess of deaths unless it were so gross that more than half the defined population had been omitted. Moreover, the number of deaths due to conditions unrelated to asbestosis was close to the estimated number and this is unlikely to have happened unless the population had been estimated approximately correctly and the deaths from all causes fully reported.

All the 11 deaths attributed to lung cancer were confirmed by necropsy and histological examination so that the excess number cannot be attributed to incorrect diagnosis among the group of asbestos workers. Some of the excess may well be due to an underestimation of the expected deaths since part of the increase in mortality attributed to lung cancer over the past 30 years is certainly due to improvements in diagnosis and in therapy (Doll, 1953). Even, however, if it were postulated that the whole of the recorded increase between 1931 and 1951 was spurious and that the real mortality from the disease throughout was that ascribed to it in 1951, the expected number of deaths is increased to only 1·1 and the observed excess is still grossly significant. For the actual number of lung cancer cases to be so little in excess of the expected as to be reasonably attributable to chance, it would be necessary for the expected cases to be 6·2, that is 5·6 times the number estimated on 1951 rates. In other words, it would be necessary to postulate that in 1951 (and throughout the previous 20 years) there was 5.6 times as much cancer of the lung as was recognized in 1931, which would mean that the condition would have to have been present and capable of detection in over 20% of all men at death. Moreover, even if this were so, it would still not account for the fact that all the cases of lung cancer were found in association with asbestosis.

It is, therefore, concluded that the fourth explanation is the most reasonable one and that the asbestos workers who had worked for 20 or more years in the " scheduled areas " suffered a notably higher risk from lung cancer than the rest of the population.

To test if the risk has altered since the 1931 regulations were introduced, it is not only necessary to make allowance for duration of employment before the end of 1932, but also to allow for the men's ages and for the total durations of their employment in the " scheduled areas ", since the men employed in the earlier periods can also have been employed longer and lived to be older. On the other hand, there is no need to consider the changing incidence of lung cancer in the total population of England and Wales since the non-industrial risk has been shown to be small in comparison with the industrial one. The data required for comparing the risks among men employed for under 10 years, for 10 to 14 years, and for 15 years and over in the pre-1933 conditions are shown in Table 5. The ages shown are the ages at death of the men who have died and the ages in mid-1953 for the men who are still alive. The expected numbers of men in each pre-1933 employment group found to have asbestosis or asbestosis and lung cancer are estimated by multiplying the numbers in each age, total employment, and pre-1933 employment subgroup by the proportions of men with asbestosis or with asbestosis and lung cancer in the same age and total employment group for all lengths of pre-1933 employment combined. For example, three out of the nine men aged 50 to 54 years who had

TABLE 5

NUMBERS OF MEN EMPLOYED FOR DIFFERENT PERIODS BEFORE 1933 AND NUMBERS KNOWN TO HAVE ASBESTOSIS AND LUNG CANCER IN ASSOCIATION WITH ASBESTOSIS DIVIDED BY TOTAL DURATION OF EMPLOYMENT IN A SCHEDULED AREA AND BY AGE

Total Length of Employment in "Scheduled Area" (years)	Age at June 30, 1953, or at Death (years)	Length of Employment before January 1, 1933									All Lengths of Employment before January 1, 1933		
		0–9 Years			10–14 Years			15+ Years					
		No. of Men	No. of Men with Asbestosis	No. of Men with Cancer of Lung	No. of Men	No. of Men with Asbestosis	No. of Men with Cancer of Lung	No. of Men	No. of Men with Asbestosis	No. of Men with Cancer of Lung	No. of Men	No. of Men with Asbestosis	No. of Men with Cancer of Lung
20–24	35–	1	—	—	1	1	—	0	—	—	2	1	—
	40–	4	—	—	1	1	—	0	—	—	5	1	—
	45–	7	1	—	0	0	—	1	1	1	8	2	1
	50–	3	2	—	3	3	1	3	3	2	9	8	3
	55–	5	3	—	2	1	—	0	0	0	7	4	0
	60–	3	1	—	1	1	—	1	1	0	5	3	0
	65–	2	0	—	0	—	—	1	1	1	3	1	1
	70–	0	0	—	0	—	—	1	1	—	1	1	—
	75–9	1	1	—	0	—	—	0	—	—	1	1	—
25–29	40–	3	—	—	0	—	—	0	—	—	3	0	—
	45–	10	2	—	2	1	1	0	—	—	12	3	1
	50–	6	2	1	0	0	0	0	—	—	6	2	1
	55–	6	1	—	8	4	0	1	1	—	15	6	0
	60–	3	—	—	1	1	0	3	3	1	7	4	1
	65–	1	—	—	1	1	1	0	0	0	2	1	1
	70–	0	—	—	0	—	—	1	0	0	1	0	0
	75–	0	—	—	0	—	—	1	1	1	1	1	1
	80–4	0	—	—	0	—	—	1	0	—	1	0	—
30–34	45–	2	—	—	0	—	—	0	—	—	2	0	—
	50–	2	—	—	5	—	—	2	—	—	9	0	—
	55–	1	—	—	1	—	—	3	2	1	5	2	1
	60–	1	—	—	0	—	—	2	1	—	3	1	—
	65–	0	—	—	0	—	—	0	0	—	0	0	—
	70–4	0	—	—	0	—	—	1	1	—	1	1	—
35+	55–	0	—	—	0	—	—	1	—	—	1	0	—
	60–	0	—	—	0	—	—	1	—	—	1	0	—
	65–9	0	—	—	0	—	—	2	—	—	2	0	—
All lengths of employment in a "scheduled area" (20 yrs.+)	35–	1	—	—	1	1	—	0	—	—	2	1	—
	40–	7	—	—	1	1	—	0	—	—	8	1	—
	45–	19	3	—	2	1	1	1	1	1	22	5	2
	50–	11	4	1	8	3	1	5	3	2	24	10	4
	55–	12	4	—	11	5	0	5	3	1	28	12	1
	60–	7	1	—	2	2	0	7	5	1	16	8	1
	65–	3	0	—	1	1	1	3	1	1	7	2	2
	70–	0	0	—	0	—	—	3	2	0	3	2	0
	75–	1	1	—	0	—	—	1	1	1	2	2	1
	80–4	0	—	—	0	—	—	1	0	—	1	0	—
	All ages	61	13	1	26	14	3	26	16	7	113	43	11

been employed for 20 to 24 years in the areas in which they might be exposed to asbestos dust were found to have asbestosis and lung cancer. Since three men had worked for under 10 years in the pre-1933 conditions, three had worked for 10 to 14 years, and three had worked for 15 or more years, the expected number of cases in each of the pre-1933 employment groups would have been the same, *i.e.*, $3 \times 3/9$, or 1. In fact, the numbers of cases found were 0, 1, and 2. The total numbers expected in each pre-1933 employment group are obtained by adding the numbers calculated for each of the age and total employment groups within it. The results are as follows :

	Length of Employment before January 1, 1933		
	Under 10 Years	10–14 Years	15 Years and Over
Total number of men with asbestosis — observed	13	14	16
Total number of men with asbestosis — *expected*	*21·9*	*10·3*	*10·8*
Number of men with asbestosis and lung cancer — observed	1	3	7
Number of men with asbestosis and lung cancer — *expected*	*5·5*	*2·4*	*3·1*

The differences between the numbers of men observed and the numbers expected in each employment group, had the incidence of the conditions remained steady throughout, are statistically significant (total asbestosis, $\chi^2 = 7{\cdot}52$, $n = 2$, $P = 0{\cdot}025$; asbestosis and lung cancer, $\chi^2 = 8{\cdot}74$, $n = 2$, $P = 0{\cdot}01$*). They are highly so if the trend, that is,

* The expected numbers of lung cancer are small and the probability that the differences could arise by chance has consequently been somewhat, but not seriously, underestimated. If all men with more than 10 years pre-1933 employment are grouped together and Yates' correction made for small numbers, $\chi^2 = 5{\cdot}82$, $n = 1$, $P = 0{\cdot}02$.

the biologically important reduction in the proportion between observed and expected numbers as the length of pre-1933 employment is reduced, is also taken into consideration. It is clear, therefore, that the incidences both of asbestosis and of lung cancer associated with asbestosis have become progressively less as the number of years during which men were exposed to the pre-1933 conditions has decreased.

The extent of the risk of lung cancer over the whole period among the men studied appears to have been of the order of 10 times that experienced by other men. This agrees well with the data reported by Merewether (1949), but it is somewhat greater than that suggested by Gloyne's data (1951). The great reduction in the amount of dust produced in asbestos works during the period has been accompanied by a reduction in the incidence of lung cancer among the workmen so that the risk before 1933 is likely to have been considerably greater—perhaps 20 times the general risk. Whether the specific industrial risk of lung cancer has yet been completely eliminated cannot be determined with certainty ; the number of men at risk, who have been exposed to the new conditions only and who have been employed for a sufficient length of time, is at present too small for confidence to be placed in their experience. It is clear, however, that the risk has for some time been greatly reduced. The extent of the reduction is particularly striking when it is recalled that between 1933 and 1953 the incidence of the disease among men in the country at large has increased sixfold.

Summary

The cause of death, as determined at necropsy, is reported for 105 persons who had been employed at one asbestos works. Lung cancer was found in 18 instances, 15 times in association with asbestosis. All the subjects in whom both conditions were found had started employment in the industry before 1923 and had worked in the industry at least nine years before the regulations for the control of dust had become effective.

One hundred and thirteen men who had worked for at least 20 years in places where they were liable to be exposed to asbestos dust were followed up and the mortality among them compared with that which would have been expected on the basis of the mortality experience of the whole male population. Thirty-nine deaths occurred in the group whereas 15·4 were expected. The excess was entirely due to excess deaths from lung cancer (11 against 0·8 expected) and from other respiratory and cardiovascular diseases (22 against 7·6 expected). All the cases of lung cancer were confirmed histologically and all were associated with the presence of asbestosis.

From the data it can be concluded that lung cancer was a specific industrial hazard of certain asbestos workers and that the average risk among men employed for 20 or more years has been of the order of 10 times that experienced by the general population. The risk has become progressively less as the duration of employment under the old dusty conditions has decreased.

I would like to offer my thanks to the management of the firm concerned for permission to carry out this work and to the Medical Officer and members of the staff of the works where the men were employed, who carried out the greater part of the work on which this report is based.

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PRIMARY LUNG CANCER IN SOUTH WALES COAL-WORKERS WITH PNEUMOCONIOSIS

BY

W. R. L. JAMES

From the Department of Pathology and Bacteriology, Welsh National School of Medicine, Cardiff

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Coal-workers in the southern part of Wales are particularly prone to pulmonary disease due to the inhalation of coal dust. In some men discrete foci of dust are scattered more or less uniformly throughout both lungs. This is called simple pneumoconiosis. In others there occur also one or more large localized masses of dust and dense fibrous tissue (Fig. 1). This manifestation is referred to as massive pneumoconiosis or progressive massive fibrosis.

The literature contains many references to the coexistence of classical silicosis with primary lung cancer, but there are few accounts of coal-worker's pneumoconiosis with coexistent tumours. In a recent statistical study Kennaway and Kennaway (1953) have shown that primary cancer of the lung is less common in coal-workers than in the general male population. Their figures also show that in the South-Western Division of the British coalfields, where the incidence of pneumoconiosis is high, the incidence of lung tumour is low relative to that in other coalfields. In some other British coalfields where the pneumoconiosis incidence is low the tumour incidence is, for coal-workers, relatively high.

The object of the present inquiry was to obtain evidence regarding the relationship, if any, of pneumoconiosis to lung cancer in South Wales coal-workers.

The material was obtained during the six years 1947 to 1952 during which necropsies were made, in this department, on 1,827 coal-workers. During the same period post-mortem examinations were made of 1,531 South Wales males over the age of 21 not concerned with coal-mining. The pathological examinations of the miners were made on the instruction of coroners who had been told by the relatives that they considered death was due wholly or partly to dust disease. The symptoms of dust disease are well known to the mining community, and requests for necropsy are likely to be made by the relatives of men who have had chronic dyspnoea. This is shown by the high incidence of chronic lesions of the lung or cardiovascular system in this series. In many of the cases pneumoconiosis of varying degrees had been detected radiologically during life, and compensation had been paid.

It was considered that useful information might be obtained by studying the material as follows :

(1) Observation of the site of the cancer in relation to the site of the massive fibrosis in those in whom the two lesions coexisted ; (2) comparing the cancer cases in the miners and non-miners in respect of the histological types of the tumours, the spread of metastases, and the age distributions at death ; (3) by studying the incidence of cancer in relation to the severity of the dust lesion ; (4) by comparing the cancer incidence in the miners with that found at necropsy in non-miners.

At necropsy one of each pair of lungs was distended by formol-sodium-acetate solution with a view to the preparation of a large section by the technique of Gough and Wentworth (1949). The other lung was cut at the time of the necropsy and after naked-eye examination pieces were excised for microscopic study.

Results

Of the 1,827 miners, 967 had simple pneumoconiosis and 860 had massive fibrosis. Primary lung cancer was found in 49 (5·1%) of those with simple pneumoconiosis and in 12 (1·4%) of those having massive disease. Of the 12 with primary lung cancer and coexisting massive fibrosis, the tumour was in the lesion, or touching it in five cases (Fig. 1), and it was remote from the lesion in the other seven. If coal dust has a local carcinogenic effect it would be likely to lead to cancer in that part of the lung in which the dust concentration is greatest, which is at the site of massive fibrosis.

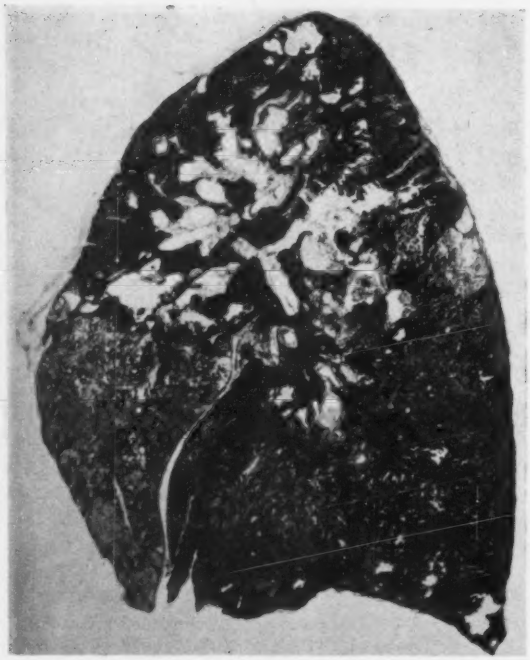

FIG. 1.—This section of the right lung of a coal-worker of 64 shows a tumour surrounded by massive dust fibrosis. The symptoms were similar to those of pneumoconiosis alone.

In those with massive fibrosis and cancer one would therefore expect to find a preponderance of the tumours in or near the dust lesion. The fact that seven of the 12 cancers were remote from dust lesions suggests that it is unlikely that the dust has a local carcinogenic effect.

Material from the lung tumours was available for microscopic examination in 56 of the lesions from miners and in 77 of the tumours found in non-miners. It was considered that if lung cancer in miners had a different aetiology from that in non-miners the difference might be shown in the microscopic structure. The lesions were therefore classified according to the methods adopted by Mulligan (1951) and Willis (1952) with the results shown in Table 1.

It is apparent from Table 1 that there is a general similarity in the distribution of the various histological types in miners and non-miners, and that if coal has any aetiological effect it is not suggested by any difference in the histological appearance.

Fifty-seven of the 61 miners with lung cancer had died from it. The distribution of metastases in the 57 was compared with that in the 82 non-miners who had died of lung cancer. Table 2 shows the number of metastases found at 12 sites in each group, with the percentage incidence. The figures

TABLE 1

HISTOLOGICAL TYPES OF 77 LUNG CANCERS IN NON-MINERS AND 56 LUNG CANCERS IN COAL-MINERS

Histological Type	Non-miners	Miners
Anaplastic only	39 (50·6%)	29 (52%)
Squamous only	32 (41·6%)	23 (41%)
Adenocarcinoma only	5 (6·5%)	2 (3·5%)
Others, including mixed types ..	1 (1·3%)	2 (3·5%)
Totals	77 (100%)	56 (100%)

show that there is a general similarity in the frequencies with which metastases are found at these sites. The greatest difference observed was in respect of the brain, where secondary lesions occurred in 27% of the non-miners but in only 9% of the miners.

TABLE 2

FREQUENCY OF METASTASES AT CERTAIN SITES IN 57 MINERS AND 82 NON-MINERS DYING FROM PRIMARY LUNG CANCER

Site	Non-miners	Miners
Lymph glands	76 (93%)	50 (88%)
Adrenals	29 (35%)	11 (19%)
Liver	25 (31%)	21 (37%)
Brain	22 (27%)	5 (9%)
Skeleton	17 (21%)	6 (10%)
Pericardium	8 (10%)	4 (7%)
Kidneys	6 (7·3%)	7 (12%)
Pancreas	4 (4·9%)	3 (5%)
Myocardium	3 (3·7%)	3 (5%)
Thyroid	2 (2·5%)	2 (3·5%)
Peritoneum	1 (1·2%)	2 (3·5%)
Others	14 (17%)	8 (14%)

Table 3 shows data relevant to the comparative frequency of death in each age group in the miners and non-miners. The figures show that the miners resemble the non-miners in that there was in both a preponderance of lung cancer in the age groups 50 to 69 years.

Whole lung sections were use to classify the 967 cases of simple pneumoconiosis into three groups showing respectively slight, moderate, and severe degrees of the condition. The classification was made by comparing each lung section with two standard sections. One of the latter was designated as the upper limit of slight simple pneumoconiosis, the other was chosen to represent the lower limit of severe simple pneumoconiosis. Table 4 shows the distribution of the cancer cases in the miners in relation to the various degrees of pneumoconiosis, and in relation to the incidence in non-miners.

Thus, taking the average incidence for all miners as 100, the incidence in miners with slight simple pneumoconiosis is 177 which approximately equals that in the group of non-mining males. The relative incidence diminishes with increasing severity of the pneumoconiosis and is least in those with massive fibrosis. It is necessary to consider whether this observed relative deficiency of cancer in miners with

TABLE 3

COMPARATIVE FREQUENCY OF DEATH RELATED TO AGE IN MINERS AND NON-MINERS

		Age Groups					
		Under 50	50 to 59	60 to 69	70 to 79	Over 79	Totals
Miners	(*a*) Total cases	349	546	675	249	8	1,827
	(*b*) Cancer deaths	8	21	25	7	0	61
	(*c*) Expected deaths	11·6	18·2	22·6	8·3	0·3	61
	100 × b/c	69	116	110	84	0	100
Non-miners	(A) Total cases	533	394	375	210	19	1,531
	(B) Cancer deaths	20	23	32	7	0	82
	(C) Expected deaths	28·7	21·1	20·1	11·1	1·0	82
	100 × B/C	70	109	159	63	0	100

TABLE 4

DISTRIBUTION OF LUNG CANCER IN 1,827 SOUTH WALES MINERS WITH VARIOUS DEGREES OF PNEUMOCONIOSIS COMPARED WITH THE INCIDENCE IN 1,531 SOUTH WALES NON-MINERS OVER THE AGE OF 21

	Simple Pneumoconiosis			Massive Pneumoconiosis	All Miners	All Non-miners
	Slight	Moderate	Severe			
(a) Total cases	524	272	171	860	1,827	1,531
(b) Cancer cases	31	11	7	12	61	82
(c) Cancers expected on the basis of all miners' necropsies..	17·5	9·1	5·7	28·7	61	51·0
100 × b/c ..	177	121	122	42	100	161

severe pneumoconiosis is true only in respect of the present series, and whether it is a result of the way in which the material was obtained. It seems possible that the method of selection resulted in the exclusion of some cases of massive fibrosis with cancer. Such exclusion is, however, unlikely since compensation is payable to the dependants if death is in any way related to massive pneumoconiosis, even if cancer coexists. Moreover, the diagnosis of cancer in those with simple pneumoconiosis is relatively easy, and in those with massive pneumoconiosis the diagnosis of coexisting cancer is radiologically difficult or impossible. Thus of the 12 with massive fibrosis and cancer, the latter was diagnosed before necropsy in only two (Figs. 2, 3, 4). Hence if cases were excluded because of clinically diagnosed cancer one would expect those with tumour and simple pneumoconiosis to be excluded, rather than those with tumour and massive fibrosis. The similarity of the cancer incidence in those with slight simple pneumoconiosis to the incidence in non-miners suggests that the diagnosis of cancer before necropsy has not been a factor in excluding miners from the present series. It would seem that in most of those cases in which cancer had been diagnosed, and in which it had even been accepted as the main cause of death, the relatives considered that dust disease might have been a contributory factor in causing death, and that a necropsy should be done.

It seemed possible that early death from pneumoconiosis might be a factor reducing the incidence of lung cancer in miners. In this connexion, of the 1,827 coal-workers studied, 469 died from dust disease alone. Of the 469, none died under the age of 30, 88 (18·7%) died under the age of 50, and only 59 (12·5%) reached the age of 70. Data published by the Registrar-General from 1949 to 1953 (average for the years 1947 to 1951) show that of males in the general population who reached the age of 30, only 9·8% died under 50, and 50·6% survived over the age of 70. Of all miners dying of dust disease it is possible that some selection takes place on an age basis and that relatively fewer of the older men are examined after death. My own experience suggests that if such selection occurs at all, the number of old men so excluded is so small that it does not disturb the general conclusion that pneumoconiosis carries a risk of death at a relatively early age. It is therefore possible that relatively early death from pneumoconiosis has the effect of reducing the incidence of lung cancer in miners in a coalfield such as South Wales where pneumoconiosis causes many deaths.

The incidence of primary lung cancer found by various authors at necropsy is summarized below.

Gooding (1946) in South Wales coal-workers	0·8%
McVittie (1949) in South Wales coal-workers	1·3%
Present author in South Wales coal-workers	3·3%
Present author in South Wales non-mining males	5·4%
Doll (1953) in general hospital necropsies on males	6·2%
Earle (1954) in American males	8·3%

Data derived from necropsy studies have the merit of accuracy of diagnosis but the disadvantage of inevitable difficulties in controlling the sample. It can, however, be said that the different incidences reported do not suggest that inhaled coal dust is carcinogenic.

Discussion

The relationship of classical silicosis to lung cancer has been studied by many authors, with divergent results. Dible (1934), Klotz (1939), and Anderson and Dible (1938) obtained pathological evidence suggesting that silicosis predisposes to lung tumour. Data suggesting that there was no

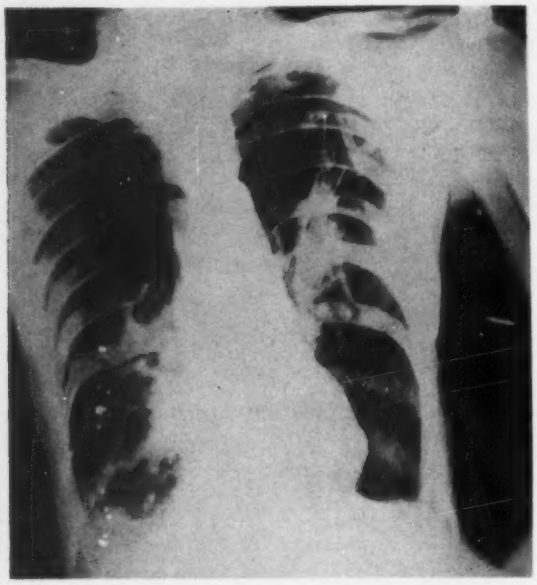

FIG. 2.—The opacity in the left lung was due to massive pneumoconiosis. The opacity in the right lower lobe was due to massive pneumoconiosis and cancer.

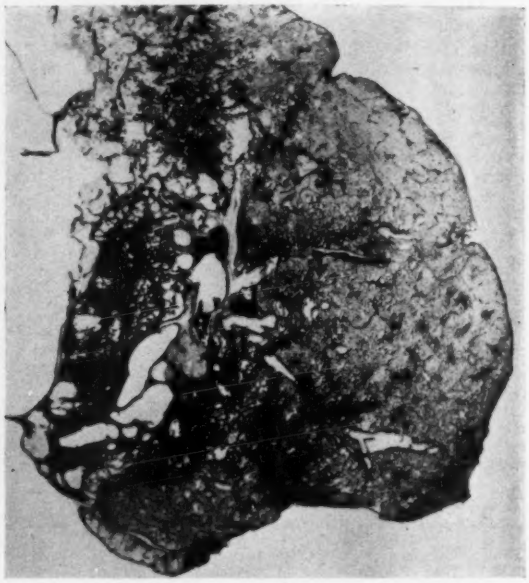

FIG. 3.—A section of the right lung of a miner aged 71, showing massive pneumoconiosis and cancer near the hilum. The radiograph (Fig. 2) was considered to be suggestive but not diagnostic of cancer.

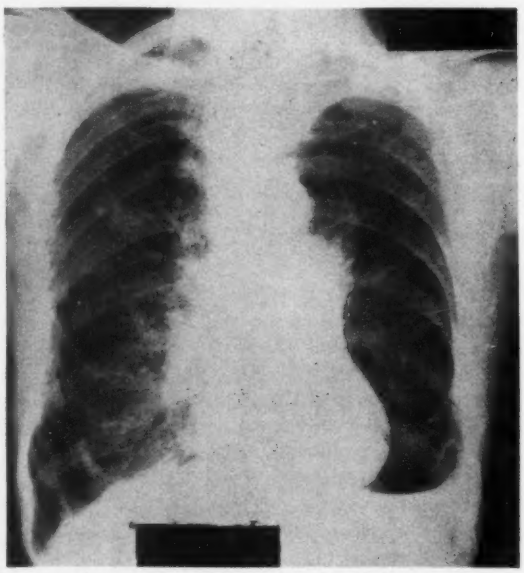

FIG. 4.—This radiograph of a coal-worker of 69 was taken 14 months before death. The lung fields show simple pneumoconiosis and a small area of massive fibrosis. The opacity in the left hilar region was considered to be due to enlargement of the hilar glands and pulmonary conus, due to dust disease. At necropsy there was a 10 cm. tumour at the left hilum.

aetiological relationship were published by Sladden (1933), Sweany, Porsche, and Douglass (1936), Vorwald and Karr (1938), the Chief Inspector of Factories (1939), Smith (1947), and Schoch (1954).

In the 30th Annual Report of the British Empire Cancer Campaign (1953) the comment is made that there is very little information about the importance, if any, of coal mining as a cause of lung cancer. Information of some relevance to the present study was published by Raeburn and Spencer (1953), who found that 11 out of 15 small lung cancers were near lung scars. The lung of the coal-worker, like his skin, frequently shows many dust-laden scars, and the infrequency of small tumours of the lung and skin in relationship to the frequent scars suggests that the coal-dust is not carcinogenic.

Stocks (1952), in an epidemiological study, observed that the comparative mortality rates from lung cancer in Merthyr Tydfil, Cardiff, and Swansea were respectively 77, 126, and 132. A large proportion of the population of Merthyr Tydfil is engaged in coal mining, whereas few coal-workers reside in Cardiff or Swansea. The total population of each of the latter is greater than that of Merthyr Tydfil, but even when allowance has been made for the known higher cancer incidence due to increased urbanization it appears that there is a relative preponderance of the tumour in the two non-mining populations.

In 1954 Blacklock, Kennaway, Lewis, and Urquhart reported on their study of the carbon content of the lungs in subjects who were not selected on an occupational basis. Part of their investigation involved the determination of the carbon content of the lungs of 26 London males, 16 of whom had lung cancer. In the cancer group the average total carbon content was 0·75 g. In the 10 without lung tumour the average carbon content was higher (0·9 g.). A similar study of the lungs of females showed that the total carbon was higher in the cancer group than in those without cancer.

The present study shows that lung cancer is found at necropsy less frequently in coal-miners than in male non-miners of the same age group. It is possible that this discrepancy may be partly due to factors in the selection of the material. It seems likely, however, that the manner in which the material was obtained would tend to increase the observed incidence of lung tumours at necropsy in the miners, since the cases are selected mainly on the basis of a history of chronic lung disease.

The fatal cases of pneumoconiosis in this series show that in such cases there is a substantial reduction in the span of adult life and therefore less risk of lung cancer. The observed relatively low incidence of the tumour may be partly due to the effect of dust disease on survival.

Summary

Primary lung cancer was found at necropsy in 3·3% of 1,827 South Wales coal-miners and in 5·4% of 1,531 South Wales non-miners.

In 12 cases of lung cancer with massive pneumoconiosis the tumour was in the mass, or touching it, in five. In the other seven the tumour was remote.

Lung cancer in South Wales miners is similar to that in non-miners in respect of the ages at death, the distribution of the histological variants of the tumour, and the distribution of metastases.

The significance of these findings is discussed. Attention is drawn to the difficulty of diagnosing lung cancer in the presence of massive pneumoconiosis.

The author acknowledges with gratitude the help of Professor Gough who provided the material and made many helpful suggestions. Dr. A. G. Heppleston assisted with useful criticism. Dr. Lewis Faning was very helpful in giving general advice regarding the statistical procedures. The photographs and lung sections were prepared by Mr. J. P. Napper and Mr. J. E. Wentworth respectively.

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PULMONARY FIBROSIS IN NON-FERROUS FOUNDRY WORKERS

BY

H. E. HARDING and A. I. G. McLAUGHLIN

From the Department of Pathology, Sheffield University, and the Factory Department, Ministry of Labour and National Service

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Much has been written about fume fever (brass caster's ague, zinc chills, zinc shakes), and lead poisoning in brass foundries has been dealt with recently by Stalker (1947) and Hamlin and Weber (1947), but the references to pulmonary fibrosis amongst non-ferrous foundry workers are few. Stalker wrote that " the incidence of advanced silicosis has been generally low among [brass] foundrymen ".

Many surveys of the incidence of pulmonary fibrosis in iron and steel foundry workers have been made, and some of them have also included groups of non-ferrous foundry workers. These include the reports by Trice and Easom (1936), Greenburg, Siegel, and Smith (1938), Sander (1939), Brown and Klein (1942), Riley, Butler, and Goren (1945) and Vigliani, Parmeggiani, and Zanetti (1948). The term " non-ferrous " includes alloys with a copper base (brass, bronze, and gunmetal) and also with an aluminium or a magnesium base. It is unusual to find specific references in these reports to brass foundries, and no pathological studies of brass founders' lungs have hitherto been reported.

Since 1936 only 10 deaths from silicosis (with or without tuberculosis) in brass workers have come to the notice of the Factory Department. But these " accidental " cases give no information about the real incidence of silicosis in this trade. Only careful surveys, which combine clinical, *x*-ray, environmental, and pathological studies, provide such information. There may well be a close analogy between the brass- and iron-founding industries. In the latter, it was thought for years that there was little risk of silicosis and other forms of pneumoconiosis, because few cases had come to the notice of either the Factory Department or the Silicosis Medical Board. When an extensive survey was made (McLaughlin and others, 1950) it was found that the incidence of silicosis and mixed-dust pneumoconiosis, particularly in moulders who made small castings, was moderately high, especially if siliceous parting powders had been used. It was also found that the dominant pathological lesion in these workers was the mixed-dust pneumoconiosis nodule and not the classical silicotic nodule.

Again, the non-ferrous metals, including brass, are cast either in sand moulds or in metal moulds (die-casting). No siliceous dust is created when die-casting takes place. If therefore the results of surveys (usually by radiography alone) of non-ferrous foundry workers are given, and no attempt made to separate the sand-casters from the die-casters, a false impression of the incidence of silicosis will be given.

In this article we present the pathological details of six non-ferrous (mainly brass) foundry workers (four moulders and casters and two fettlers) together with such clinical, radiological, and environmental details as were available. In five instances the casting of the various metals was done in sand moulds and in the sixth in iron moulds.

Case Histories

Case 1.—C. C. was aged 60 years when he died. He had been employed as a moulder and caster of non-ferrous metals (brass, bronze, aluminium) for 29 years up to 1942 when he became a charge-hand and thereafter did only a little moulding. In this foundry Mansfield red sand is used for making moulds. Accurate information about parting powders was difficult to obtain, but that used from 1920 until about 1940 was said to consist of ground fireclay bricks (60% free silica) and furnace ashes. Since that time a parting powder with a total silica content of 0·3% has been used.

He began to have " chest trouble " two years before his death. He attended a chest clinic in May, 1945, where he was found to have pulmonary tuberculosis. Tubercle bacilli were found in his sputum on four occasions. An *x*-ray film of the chest taken at this time showed the presence of " fibroid tuberculosis " in both lungs. The report was " very marked fibrosis

of the lungs. Large hazy patches extending from both roots into the upper lobes show marked calcification". The appearances also suggested the presence of silicosis, and inquiries about the man's occupation were made. He was admitted to hospital in August, 1945. Further *x*-ray examination was made in October, 1945, and the report was of " silicosis of the lungs with definite tuberculous infiltration in both mid-zones ". He died in November, 1945, having last worked in July of the same year.

To the naked eye the lungs after fixation showed fibrous adhesions over most of both lungs and acute pleurisy over the basal areas where fibrosis was absent. The lungs were bulky with some emphysematous bullae : ragged cavities were present in the apical portion of each lobe of the left lung, and tuberculous bronchopneumonia was evident throughout both lungs. Also seen throughout both lungs were numerous small, hard, black areas most of which were intimately associated with tuberculosis, but a few in the lower parts appeared separate from the infectious process.

Microscopical examination showed tuberculosis of varying age, considerable silico-tuberculous nodulation (Fig. 1) and areas of fibrosis that appeared purely silicotic.

FIG. 1.—Case 1 : tuberculo-silicotic nodule with focal emphysema. Haematoxylin and eosin. × 4.

Case 2.—H. R. was 54 years old when he died in November, 1948. At the age of 13 years he went to work in the office of a firm of brass founders, and after a short time became a brass moulder. He continued at this job for about 15 years, when he was out of work

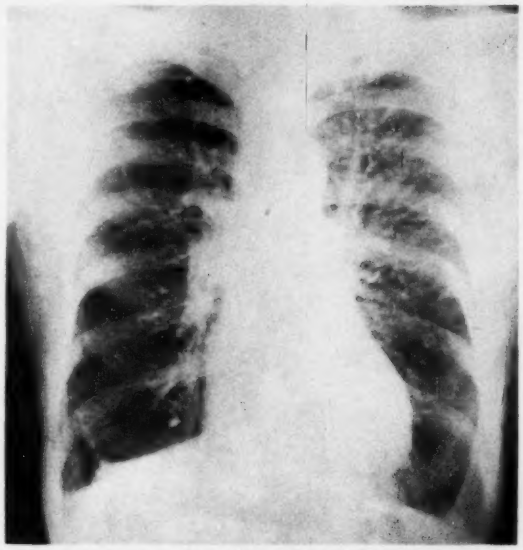

FIG. 2.—Case 2 : *x*-ray film of the chest (1946) showing generalized increased linear striation with some reticulation.

for a period. He returned to his job as a brass moulder and continued as such until six years before his death when he became " ill with his chest " and was in hospital for six months. He then returned to his work for a few months, but had not worked thereafter. He was engaged in brassmoulding for about 32 years. The parting powder used during the first period of his working life was sieved burnt sand, and during the second a proprietary non-siliceous preparation.

Little information is available about his illness. He is known to have attended a chest clinic and no evidence of tuberculosis was found. Two *x*-ray films of the chest are available, one taken in May, 1942, and the other in December, 1946 (Fig. 2). The first film showed increased linear striation with some fairly large opacities at both bases. There were more abnormal shadows, especially at the bases, in 1942 than there were in 1946. It is likely that in 1942 he was suffering from a form of subacute pulmonary congestion which had cleared by 1946. The second film (Fig. 2) shows generalized increased linear striation with some reticulation, but no nodulation. There is " peaking " of the right diaphragm, suggesting the presence of adhesions. This was seen also in the earlier film.

At necropsy the body was very wasted, and all the organs were wasted except the thyroid, which was moderately enlarged : the heart, which weighed 12 oz., showed dilatation with some hypertrophy of both ventricles. The lungs showed marked emphysema with much pigmentation, some small palpable black nodules, and acute bronchitis.

Microscopically the lungs showed both a generalized and some focal emphysema with small but definite areas of pneumoconiotic fibrosis (Fig. 3). A hilar lymph node showed linear fibrosis amongst pigment.

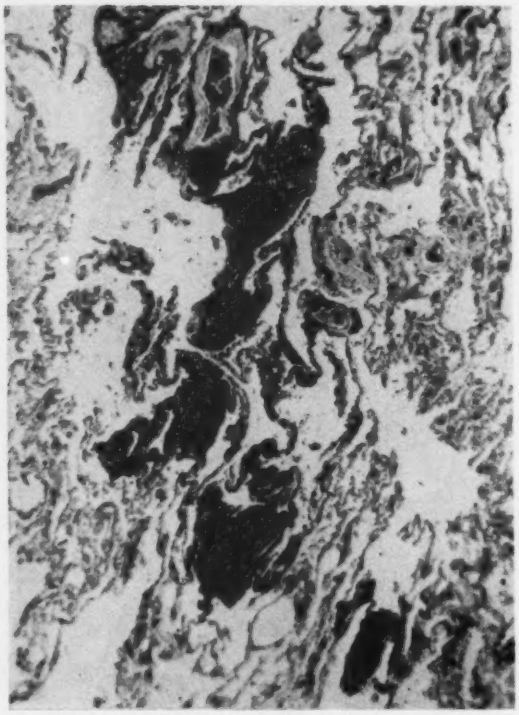

FIG. 3.—Case 2: early mixed-dust fibrosis and focal emphysema. Haematoxylin and eosin. × 30.

Case 3.—P. T. was aged 56 years when he died in January, 1950. He had been a caster of copper pipes for 31 years at one works and previously for a few years had been an under-hand at a brass foundry. Before this he had worked on the railway for a few years after leaving school. His main work had consisted in pouring molten copper into "cannon type" iron moulds, which were lined with a mixture of plumbago and oil, and without any added siliceous material. Plumbago, or natural graphite, usually contains a small percentage of free silica. The moulds were water-cooled before the castings were removed. Apart from frequent attacks of metal fume fever he was said to have enjoyed good health until 1945 when he was forced to give up his work because of dyspnoea. In June, 1949, he was admitted to hospital for six weeks. He gave a history of gradually increasing breathlessness on exertion, cough, loss of weight, and joint pains over the previous four or five years; swelling of the legs for two months, and cyanosis for two weeks.

On examination he was thin, wasted, and orthopnoeic. The heart was enlarged and there were signs of emphysema and congestion at the bases of both lungs. There was gross oedema of the legs. Blood pressure was 160/110 mm. Hg.

An *x*-ray examination on June 13, 1949 (the film is not available), showed that "the cardiac outline appears a little larger than usual and there is well-marked calcification in the arch of the aorta. The lung fields show a generalized increase in the markings with obliteration of the right costophrenic sulcus. This picture could well fit in with the previous occupational history. There is no evidence of active tuberculosis". A blood count was within normal limits; an electrocardiograph tracing showed right axis deviation. The signs of cardiac failure cleared up during treatment in hospital and he went home where he died six months later.

The fixed specimens showed old pleural adhesions, especially at the bases of the lungs: the pleura elsewhere was black with fairly noticeable white lymphatic markings. The lungs showed much black pigment, had marked emphysema both focal and general, but contained no palpable nodules. There was acute bronchitis more marked in the upper parts of the lungs. The hilar lymph nodes were large, very black, and moderately firm. No tuberculosis was visible.

Microscopically there was diffuse thickening of the alveolar walls in the lungs, largely cellular but with some collagen and with fairly numerous foreign body giant cells which were not particularly associated with pigment. There were some small areas of mixed-dust fibrosis. The hilar lymph nodes were markedly congested; they contained a fair amount of pigment but showed little fibrosis.

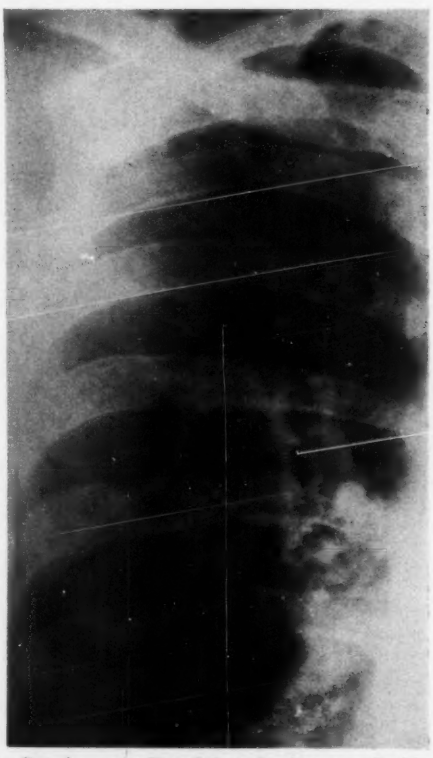

FIG. 4.—Case 4: *x*-ray film of chest showing generalized increased linear striation with a background of reticulation in right upper zone.

Case 4.—J. J. G. was 50 years old when he died on December 20, 1952. He left school at 14 years of age and was a brass moulder nearly all his working life, with the exception of three years between 1936 and 1939 when he worked at the docks as a ship's plumber. At his last factory, where he had worked for 12 years, he had done nine years "floor" moulding and three years core making. Altogether he had been a brass moulder for nearly 40 years. No information about the parting powders used in the foundries is available.

About two years before his death he began to get short of breath and he consulted his doctor who sent him for *x*-ray examination. It was reported that the chest film showed the presence of pneumoconiosis (Fig. 4). The picture is one of increased linear striation with a background of reticulation. He refused to apply for compensation, and he went back to work and continued with increasing difficulty owing to dyspnoea until October 11, 1952, when he could no longer work. He died at home two months later.

The fixed lungs showed marked apical and marginal emphysema; in addition there was focal emphysema around small pigmented areas which were doubtfully palpable. The bases were congested and partly autolysed. The hilar lymph nodes were soft and not very pigmented.

Microscopically the lungs showed acute bronchopneumonia. There was slight pneumoconiosis with slight focal emphysema. The sections showed comparatively little pigment, of which a little was iron and only a very little silica.

Case 5.—G. E. G. was 76 when he died in January, 1954. He worked as a brass fettler for 45 years, giving up work in 1952. In early life he spent eight years in various jobs that did not carry a risk of pneumoconiosis. His health had been good until the end of 1951 when he noticed that he was short of breath on effort, and he developed an intermittent cough. In 1952 he was found to have a blood pressure of 220/100 mm. Hg and an enlarged heart with a systolic murmur. An *x*-ray examination (Fig. 5) in May, 1953, showed that there was coarse nodulation in both lungs while below the right clavicle there was massive fibrosis. His death was reported as due to coronary occlusion from coronary atherosclerosis with silicosis of the lungs as an accessory factor.

The lungs after fixation showed a dense, white ("sugar icing") thickening of the pleura in irregular patches at the apices and elsewhere, the largest patch being 1 in. in diameter: in addition there were many small, white, palpable dots on the blue-black pleura. In the right lung was a mass of conglomerate nodules below the apex about 2 in. in diameter and showing a little ischaemic necrosis at the centre; hard, rounded, black nodules about ¼ in. in diameter, forming occasional small agglomerates, were scattered throughout the lung lessening in number towards the base. Focal emphysema was not a conspicuous feature but there was fairly notable emphysema at the base of the lung. The left lung was similar to the right but not so badly affected. No evidence of tuberculosis was seen in either lung. The

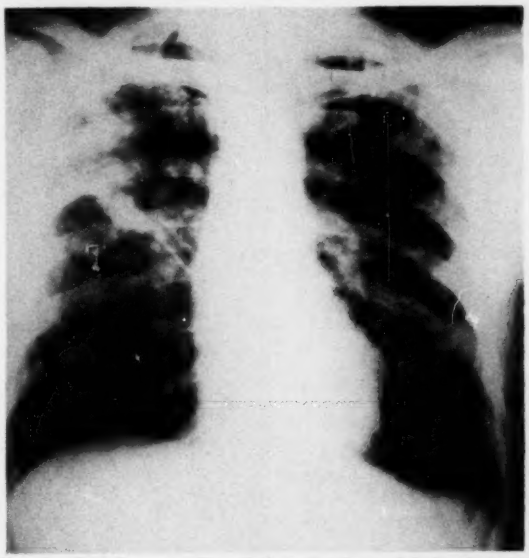

FIG. 5.—Case 5: *x*-ray film of chest showing nodulation in upper two-thirds of both lungs, with a massive shadow in the right upper lobe, and translucent areas at both bases suggesting the presence of bullous emphysema.

hilar lymph nodes were moderately enlarged, black, and very firm.

A large section of the left lung (Fig. 6) shows nodular silicosis and also some stellate nodules of simple pneumoconiosis with focal emphysema. Microscopically (Figs. 7, 8) the lungs show whorled silicotic nodules tending to aggregate and also linear dust fibrosis.

Case 6.—N. T. was aged 56 years when he died in 1954. On leaving school he was apprenticed to a brush maker for three years. He was an iron fettler for nearly three years, he did a year's military service, and then had two more years as an iron fettler. He was then unemployed for 15 months, and afterwards worked as a domestic gardener for nearly six years. From June 22, 1928, until July 14, 1952, *i.e.*, for 24 years, he worked as a bronze fettler for a firm in the Sheffield area. He gave up work two years before his death on account of a chest illness. An *x*-ray film (Fig. 9) taken in June, 1952, shows coarse reticulation with some nodulation in the upper two-thirds of both lungs. A well-marked "honeycomb" appearance is seen in the mid-zones, there is increased translucency over the lower thirds of both lung fields, and irregularity of both diaphragms, suggesting emphysema and diaphragmatic adhesions.

The bronze foundry in which he worked for 24 years is housed in a bay of a large building which also contains a steel foundry. The ventilation arrangements for the removal of melting and casting fume are now excellent but have probably not always been so. The moulds for casting are made partly of cement and partly of sand. Little visible burnt-on sand remains on the castings after they have been knocked out of the mould. Fettling is done mainly by pneumatic chisels, but also by portable grinders. Exhaust ventilation is not applied to these

FIG. 6

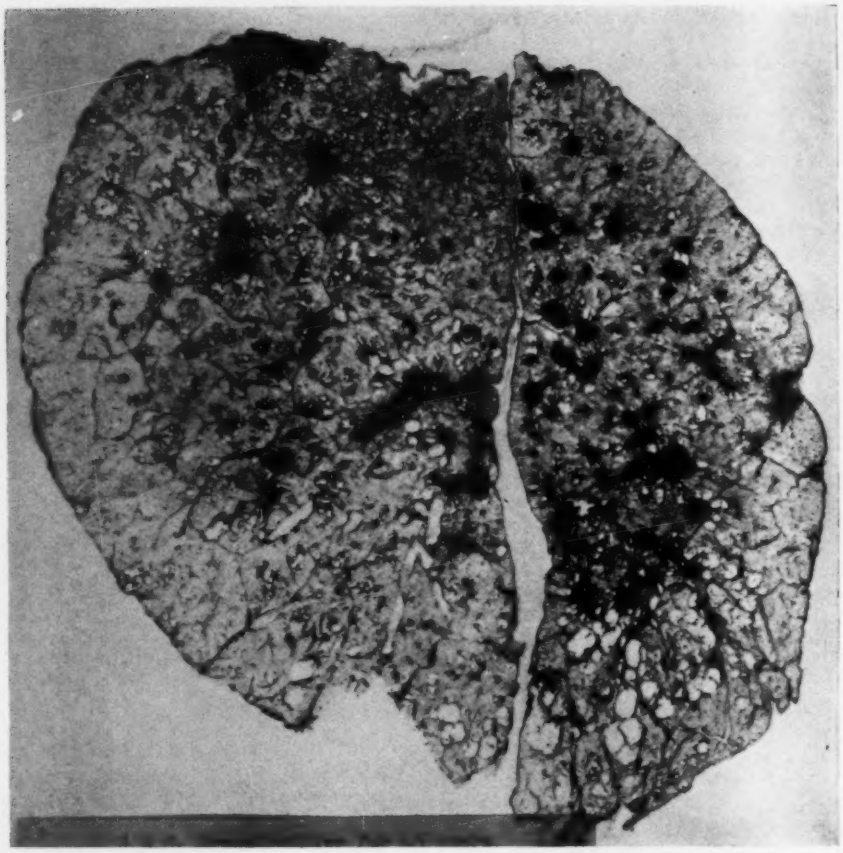

FIG. 6.—Case 5 : section of left lung showing well-marked silicotic nodulation with some stellate nodules of mixed-dust fibrosis. Approximately half natural size.

FIG. 7.—Case 5 : agglomerate silicotic nodule. Haematoxylin and eosin. × 10.

FIG. 8.—Case 5 : mixed-dust fibrosis (simple pneumoconiosis) and focal emphysema. Haematoxylin and eosin. × 24.

FIG. 7

FIG. 8

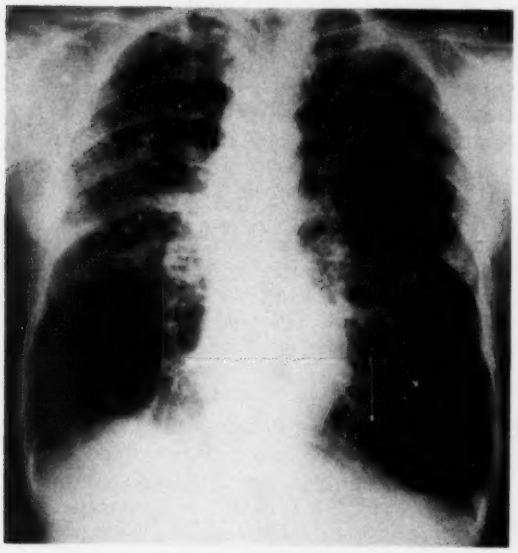

FIG. 9.—Case 6: *x*-ray film of chest showing "honeycombing" with some nodulation and reticulation in upper two-thirds of lungs.

FIG. 10.—Case 6: Bronchiectatic cavities surrounded by fibrosis together with silicotic nodulation and focal emphysema. Haematoxylin and eosin. × 13.

tools. Fettling is also done by large abrasive wheels to which exhaust ventilation is applied.

After a post-mortem examination, Dr. D. Guest reported that death was due to "toxaemia and heart failure from bronchopneumonia, associated with silicosis of the lung and chronic purulent bronchitis".

To the naked eye the fixed lungs showed many pleural adhesions, widespread bronchiectasis with bronchopneumonia, and several abscesses: some small fibrous nodules were palpable in each lung apparently distinct from the fibrosis due to bronchiectasis.

Microscopically (Fig. 10) the lungs showed bronchiectasis, bronchopneumonia with abscess formation, some whorled fibrous nodules, and slight simple pneumoconiosis with focal emphysema.

Chemical Analysis of Lungs

The results of chemical analysis are given in the Table and are expressed as percentages of dried weight of lung. They are not necessarily comparable with those of other authors. All the lungs had been in fixative (formol-saline), often for long periods, and had been cut into in many places before samples were taken for analysis. An attempt was made in each case to get a representative sample of the whole of both lungs: no chemical analyses were made of fibrous areas alone. It may be noted that there was a rough correlation between the percentages of free silica and the amount of fibrosis (both whorled and linear) found in the lungs. The free silica estimations were made by the method of Trostel and Wynne (1940); the other estimations by standard chemical methods. No appreciable quantity of zinc or copper was present in the ash of the lungs.

TABLE
RESULTS OF CHEMICAL ANALYSIS OF LUNGS

Case	Ash	Total Silica	Free Silica	Iron (as Fe_2O_3)
1	4·45	1·39	0·55	0·59
2	3·34	0·35	0·11	0·49
3	4·51	0·16	0·02	1·3
4	1·45	0·10	0·06	0·33
5	5·11	1·2	0·60	1·21
6	4·15	0·82	0·58	1·51

X-ray analysis of the ash of Case 5 showed 7% of quartz (*i.e.*, 0·36% of dried lung), while analysis of a nodule from the lung showed 1·5% of the dry weight to be quartz.

Discussion

The conclusions which can be drawn from the study of this small series of cases can only be tentative, but it seems reasonable to assume that many of the pathological changes found can be related to the occupation. Brass and bronze moulders and casters who work with sand moulds are exposed to the inhalation of dusts and fumes

which may vary quantitatively and qualitatively with the conditions of ventilation and the technique of moulding and casting in the individual shop. The sand used has usually a lower free silica content (about 80%) than that used for steel castings (about 95%), because the melting temperatures of these non-ferrous metals are lower than that of steel and iron. The melting temperatures are also relevant in the cases of fettlers, because they largely determine whether or not burnt-on sand will be left on the castings. It is the dust created by vigorous methods for removing the sand from the castings which causes silicosis and mixed-dust fibrosis.

Moulders and casters are also exposed to the inhalation of dusts caused by the application of parting powders and mould dressings. The Foundries (Parting Materials) Regulations came into force in 1950 and they prohibit the use of parting powders containing more than 3% of compounds of silicon. Before that date siliceous parting powders were freely used, though many parting powders used before 1950 were silica-free. Many proprietary parting powders are on the market, and contain such substances as zirconium silicate, calcium carbonate, calcined china clay, sillimanite, fused alumina, and olivine.

These workers are also invariably exposed to the inhalation of freshly formed zinc oxide and to a lesser extent to the oxides of other metals such as copper, tin, and lead. Some, but not all, brasses contain lead, but none of the cases described in this paper had suffered from lead poisoning.

Of the four moulders and casters, the immediate cause of death in two was bronchopneumonia (one tuberculous) and in the other two cor pulmonale or right-heart failure. All four had marked emphysema, both general and focal, associated with bronchitis. It may well be that emphysema and bronchitis arise partly or mainly from the inhaled dusts and fumes, though it is difficult to produce convincing evidence. But an agent which irritates the pulmonary tissue is also likely to irritate the bronchial mucous membranes.

The amount of occupational fibrosis found in the lungs of the moulders varied. In one case there was well-marked silicosis (associated with tuberculosis); in two others there were definite though not severe areas of mixed-dust fibrosis (which we regard as modified silicosis), and in the fourth there was only slight mixed-dust fibrosis. The man who had the shortest exposure to brass moulding and casting (29 years) had the most marked fibrosis, but he was known to have used a siliceous parting powder for some years. The other three patients had been employed for 32, 31, and 40 years respectively. It is not known for certain if they had used siliceous parting powders, but inquiries suggest that if they had, large quantities were not used. These three men, however, would be exposed to dry siliceous dust arising from the process of knocking away the sand moulds and cores after casting. Such dust might well account for the mixed-dust fibrosis or modified silicosis found in their lungs.

The two brass fettlers or dressers both had silicotic nodules in the lungs. One (Case 5), who had been doing the work for 43 years, developed moderately marked silicosis with some mixed-dust fibrosis and focal emphysema. There was also some gross emphysema at the bases of the lungs. The immediate cause of death was coronary thrombosis. The other (Case 6) had worked for 24 years as a bronze fettler and five years as an iron fettler. Death was mainly caused by bronchopneumonia associated with bronchiectasis and abscess formation: however, some fibrous nodules, both of the silicotic and mixed-dust fibrosis types, were present in the lungs.

Though there is not a great deal of visible burnt-on sand on brass castings there is enough to cause some pulmonary fibrosis amongst the fettlers. Our general impression from these cases and our previous studies of iron fettlers (Harding, Gloyne, and McLaughlin, 1950) is that the lungs of iron fettlers become damaged more quickly than those of brass fettlers. This is consistent with the fact that the melting temperature of iron is higher than that of brass and therefore more burnt-on sand is found on iron castings.

The pathological features of these lungs are similar to those found in workers in iron and steel foundries (Harding and others, 1950). Simple pneumoconiosis or mixed-dust fibrosis accompanied by focal emphysema as in colliers' lungs is the commonest finding. True whorled silicotic nodules are also occasionally found, as well as transitions between the stellate nodules with linear or radial fibrosis and the classical nodules with whorled dense fibrosis. Both types of lesion are seen in the lungs of Case 5, and possibly represent differences in the silica content of the dust at different periods. As with pneumoconiosis in other trades, tuberculosis and other infections seriously complicate the picture.

Summary

Clinical, radiographic, environmental, and pathological (gross, histological, and chemical) details of six non-ferrous foundry workers (four moulders and casters, and two fettlers) are described.

All six cases showed varying degrees of occupational pulmonary fibrosis, either whorled silicotic nodulation, linear or stellate fibrosis (mixed-dust fibrosis), or transitional stages between these two types of fibrosis.

Though all cases showed fibrosis, it was a clear factor in the deaths of only two of them (Cases 1 and 5) ; it was doubtfully so in two others (Cases 2 and 6) and was insignificant in the remaining two (Cases 3 and 4).

The pathological features of the lungs of non-ferrous foundry workers are similar to those found in iron and steel foundry workers. Both moulders and fettlers are liable to contract silicosis and mixed-dust fibrosis which may be complicated by pneumonia, tuberculosis, and chronic bronchitis and emphysema with right-heart failure.

We are indebted for much help in collecting information about these six cases to the following : Dr. P. K. Walker, Dr. S. Bryson, and Dr. H. Blyth, of the Pneumoconiosis Panels, Ministry of Pensions and National Insurance ; Dr. W. D. Buchanan, H.M. Medical Inspector of Factories, Ministry of Labour and National Service ; the Records Officer, Leeds General Infirmary, for clinical details of Case 3 ; Dr. H. Midgley Turner, Chief Chest Physician, Sheffield, for clinical and radiographic details of Cases 1 and 2 ; Dr. R. Hardy, Chief Chest Physician, Hull, for the *x*-ray film of Case 4 ; and to Dr. Denton Guest, Huddersfield, and Dr. A. P. Massie, Hull, for additional pathological details about Cases 4 and 6 respectively. Part of the expenses of this investigation was met by a grant to one of us from the Research Fund of the University of Sheffield. The photomicrographs were made by Mr. A. W. Collins, F.I.M.L.T.

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LEPTOSPIRAL SEROLOGY IN SCOTTISH COAL-MINERS

BY

R. S. F. ADAM and P. N. EDMUNDS

From the Medical Service, Scottish Division, National Coal Board, and the Department of Bacteriology, Edinburgh University

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The problem of leptospiral infection in coal-miners became prominent in one area of the Scottish coalfields during the period 1940–52 when altogether 15 cases of Weil's disease were diagnosed or suspected in colliery workers out of a total man-power of some 8,000. Of those 15 cases, 11 were reported from a single colliery and four of these 11 died.

Serological confirmation of the diagnosis was obtained in four of the non-fatal cases, but the swift course of the illness in the fatal cases did not permit the patients to survive long enough to enable typical antibodies to be detected. The clinical findings in most of the cases left little doubt as to the true nature of the disease. All those concerned were underground workers and worked in collieries known to harbour rats.

The incidence of leptospirosis in rats in Scotland has been estimated at 44% of 117 rats in the Aberdeen district by Smith (1938) and 37% of 166 wild rats in East Lothian by Buchanan (1927). Since infected rats are known to shed numerous leptospirae in their urine over a long period, there was a strong possibility of frequent contamination of the pit with *L. icterohaemorrhagiae* and hence extensive contact with infection among the workers.

In view of this, the relative rarity of clinical Weil's disease (an average rate over the 12 years of 0·02% per annum of 8,000 men in the area concerned) led us to investigate the possibility of the occurrence of further unrecognized infection. This possibility was illustrated by one of the Scottish cases which showed little constitutional upset and no jaundice, the diagnosis being established by a mounting titre of antibodies reaching eventually 1 in 10,000 for *L. icterohaemorrhagiae*. As far as subclinical infection is concerned, Smith and Davidson (1936) showed that 51 of 210 fish workers in Aberdeen gave serological evidence of previous infection with *L. icterohaemorrhagiae*. Of these 51 sera, 18 (8·6% of total) came from individuals with no clinical history. From the data supplied in a paper by Tiffany and Martorana (1942) on the incidence of leptospiral agglutinins in New York sera, the rates for positive findings among sewer workers and fish workers, showing no previous history of Weil's disease, were 11 of 515 (2·1%) and seven of 102 (6·9%) for these respective occupations.

There appears to be no information available in the literature as to the occurrence of leptospiral agglutinins in the sera of normal coal-miners in Scotland.

Sampling Methods

The colliery at which 11 of the cases had been reported was chosen and an attempt made to obtain a random sample of the pit population for serological investigation. Surface as well as underground workers were included in the sample, partly because surface work may itself involve some exposure to risk, and partly because many surface workers have spent appreciable periods in underground employment in the past. The colliery employed a total of about 2,700 men and of this number 400 were employed on the surface. It was decided that a sample including 5 to 10% of the total workers would be sufficient.

Each man in the colliery is normally issued with a number by which he may be identified, and the sample was obtained by selecting every twentieth number and then inviting the man concerned to take part in the investigation. In the event this system produced only about half of the volunteers expected and so it was found necessary to repeat the sampling on a further set of numbers selected on an identical basis to obtain finally 201 samples.

This development tended to destroy the random nature of the sample and in fact it appeared that the younger workers were more willing to come forward than the older men, as Fig. 1, which compares the age distribution in the sample with that of the general pit population, shows.

On the other hand, 65% of the sample population lay between 30 and 59 years while 71% of the pit population lay between these same ages. Again, 81% of the sample

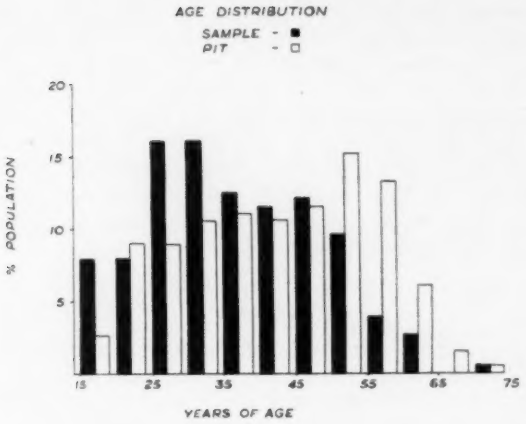

FIG. 1

lay between the ages of 25 and 59 years, this group comprising 80% of the pit population.

Thus, even though the age pattern of the sample is not identical with that of the total colliery population, the working experience of the sample does represent a considerable exposure to risk, the 163 men aged 25 to 59 having put in 2,000 man-years at the colliery concerned and a further 2,800 man-years in mining service, for the most part underground.

Bacteriological Methods

Serological tests were performed on the blood samples at the Bacteriology Department, Edinburgh University.

Serum dilutions in normal saline were mixed with equal volumes of freshly prepared formolized three- to seven-day-old cultures in Korthof's medium (Mackie and McCartney, 1953) of *L. icterohaemorrhagiae* (Wijnberg and Jackson strains) and *L. canicola* (Berlin). The final dilutions ranged from 1 in 10 upwards. The mixtures were kept in the refrigerator overnight and read by dark-ground microscope. This technique is the one used routinely by Broom (1952). When positive results were obtained the tests were repeated with further specimens of serum and also using live cultures. During the period of the investigation the strains of leptospirae used were tested several times with standard preserved rabbit anti-sera and no significant differences in titre were observed for any one strain at different times. Two strains of *L. icterohaemorrhagiae* (AB) were used in case any sudden change in sensitivity occurred in either, although no such change was in fact observed at any time.

Results

Table 1 shows the details of positive serological findings. It will be seen that only miners Nos. 63 and 119 gave results which were confirmed on subsequent repeated tests. In both cases the maximum titre obtained was 1 in 90 when live suspensions were used.

Miners Nos. 63 and 119 were, therefore, considered definitely positive and Nos. 87 and 83 as doubtful positive. The only serum giving any reaction with *L. canicola* was the second sample of miner No. 119 which gave agglutination of a live suspension to 1 in 10 only. Titres against Wijnberg and Jackson strains of *L. icterohaemorrhagiae* were the same with the exceptions shown at the foot of Table 1. Miner No. 63 was a coal-face worker, aged 44 years, who had spent some 12 years in mining and had suffered no illness suggestive of Weil's disease. The second man, No. 119, also an underground worker, aged 46 years, had spent all 33 years of his working life at the one colliery. There was a history of undefined illness of an influenzal character 10 years previously when he had been off work for one month. Jaundice had never been observed at this or any other time.

TABLE 1

DETAILS OF POSITIVE SEROLOGICAL FINDINGS

Case	Date of Serum Sample	Titre *v.* *L. icterohaemorrhagiae*	
		Formolized Culture Used	Live Culture Used
Miner No. 63	27. 5.53	30*	30
	22. 6.53		30*
	10.11.53	30	90
Miner No. 119	26. 8.53	10	30
	15. 4.54		90†
Miner No. 87	11. 6.53	30	30
	29. 6.53		Negative
	10.11.53	? 10	10
Miner No. 83	10. 6.53	? 10	10
	29. 6.53		Negative
	16.12.53		Negative

Titres are expressed as the reciprocal of the final serum dilution at the end-point.
* Titre against Jackson strain was 1 in 10.
† Titre against Jackson strain was 1 in 30.

Discussion

Evidence for the specificity of low-titre leptospiral agglutination reactions in the sera of normal people is provided by Smith and Davidson (1936) who found no agglutination at a 1 in 10 dilution by the sera of 403 controls, by Stuart (1946) who never found antibodies at a dilution of 1 in 10 in people not exposed to known or highly probable leptospiral infection, and by Ward and Turner (1942) who, in a survey of workers in different trades, accepted an agglutination titre of 1 in 10 as evidence of previous infection. Broom (1948) showed that out of 875 patients suffering from diseases other than Weil's disease, only 23 gave titres of 1 in 10 or more, and most of these worked at occupations where Weil's disease is a recognized hazard, so that the possibilities of previous contact with leptospirae could not be ruled out.

It therefore seems certain that miners Nos. 63 and 119 had had previous unrecognized infection

with *L. icterohaemorrhagiae* and there is a definite possibility that miners Nos. 87 and 83 had also had subclinical infections. The occasion of the original infection of miner No. 119 may well have been the influenzal illness 10 years before, which must have been a fairly severe one since, (*a*) he remembered it, and (*b*) he was off work for a month with it.

Although one cannot rule out completely the possibility that miners giving a negative serological reaction may yet have had previous leptospiral infection, the evidence shows that leptospiral agglutinins persist in the serum for long periods after infection. Thus, Kisker (1935) found positive agglutination from two to 16 years after recovery from Weil's disease, Uhlenhuth and Fromme (1930) after 22 years, and Stuart (1939) after 28 years. Broom (1948) found agglutinins in all cases which he examined following recovery (up to four years in one case). Whether this applies equally in the case of subclinical infection is not definitely known, but miners Nos. 63 and 119 in the present series gave a definite reaction of slightly higher titre than the original level, six months and eight months respectively after the first specimen was examined, indicating that no decline in titre had occurred during that period. It therefore seems probable that the miners giving negative reactions had not had leptospiral infection during their previous mining experience.

The findings of this investigation have provided serological evidence of two cases (1% of sample) of leptospiral infection undiagnosed at the time ; one with, and one without, a history of illness which could retrospectively be attributed to leptospiral infection. In view of the weighting of the sample with workers of age group 15 to 34 who had been exposed to the risk of leptospiral infection for a shorter time than those of the relatively less well represented age groups 50 to 69, this figure is probably on the low side. On the other hand none of the 33 sample miners of the older age group showed definitely positive results, the only two confirmed reactions occurring in the age group 40 to 49, a group which was in fact fully represented in the sample. The present figure compares with the 8·6% among Aberdeen fish workers quoted above (Smith and Davidson, 1936), the 6·9% of Tiffany and Martorana (1942) for New York fish workers, and the 2·1% of New York sewer workers also obtained from the last authors' results.

Summary

Sera were examined for leptospiral agglutinins from 201 normal coal-miners working in a Scottish pit in which 11 cases of Weil's disease had occurred during 1940–52.

Sera from two of these miners agglutinated *L. icterohaemorrhagiae* to a titre of 1 in 90 and a further two gave doubtful results.

At least 1% of the sample population had had unrecognized infection with *L. icterohaemorrhagiae*.

Acknowledgments are due to Professor T. J. Mackie, Dr. C. G. Gooding, and Dr. H. A. Wright for their advice and criticism, also the National Coal Board, Scottish Division, who instigated the investigation, and to the trade unions and the workmen who volunteered, for their cooperation.

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*DIURNAL VARIATION IN MENTAL PERFORMANCE

A STUDY OF THREE-SHIFT WORKERS

BY

BO BJERNER, ÅKE HOLM, and ÅKE SWENSSON

From Division of Occupational Medicine, Karolinska Hospital, Stockholm, Sweden

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A great deal of research has been done on the diurnal variations in different forms of animal and human activity. The first diurnal variation to be observed was the one in body temperature, and it is the one most widely recognized today. Similar diurnal variations have been observed in a series of other physical processes. Extensive surveys of the literature have been given by Holmgren (1936), Jores (1937), and Kleitman (1939, 1949).

A series of investigations has also been carried out on diurnal variations in mental performance. At first these investigations were done by psychologists independently of physiological research. Freeman and Hovland (1934) gave an exhaustive review of the literature and assembled the contributions of different workers in a table in which the forms of variation observed were divided into different classes. As Kleitman (1939) remarked, " No matter what curve one obtains, there is a convenient niche in Freeman and Hovland's table for it ". The main reason for the variety of curves is that most of the series studied are so small that chance variations have played too great a part. Kleitman and his associates made a thorough study of the variations in mental performance during waking hours. Kleitman stated that all the curves they obtained fitted into class C of Freeman and Hovland, namely, " a peak in the middle of the waking period ". He believed that the fluctuations in mental performance were caused by variations in body temperature. In 1949 one of us studied the reaction time in five subjects kept awake for 24 hours and longer (Bjerner, 1949). Two of them showed a regular curve with a peak in the length of reaction times and a number of false reactions at 4 a.m. The other three showed longer reaction times during the night but no distinct diurnal variation. This was the first study of this kind to be made during the night.

Another branch of these investigations, apparently done independently of the two others, is the research begun about 1900 on the spontaneous activity of animals during day and night. A distinct diurnal variation has been observed, which, however, is easily influenced by external stimuli such as light and darkness. If the night is made light and the day dark, the animal quickly inverts its rhythm of activity. This takes place by a gradual displacement of the activity, in rats completed within a week after the change in illumination (Holmgren and Swensson, 1953).

In general it may be said that studies of the diurnal variation of different functions have sometimes given greatly conflicting results and the theoretical aspects of the problem have not as yet been satisfactorily elucidated. Obviously, however, variations of this kind must be of great significance in everyday life, especially when it comes to night work and/or shift work. But, very few studies have been done on this particular aspect of the problem and none of them has given results of any great practical importance.

The most extensive studies were done in England during and after the first world war. The results are given in the Final Report of the Health of Munition Workers Committee (Ministry of Munitions, 1918) and in reports of the Industrial Fatigue Research Board (1919–22). They have been summarized by Vernon (1921, 1940).

One of the main objects of the Health of Munition Workers Committee was to study whether there was any difference in working efficiency during day and night. Several different series of investigations were done and it was found that sometimes the production was higher in night shifts and sometimes higher in day shifts.

It was observed that when women had monotonous work, requiring little physical effort, the production in discontinuous night work about equalled that for the same kind of work during the

* The term " diurnal " is used here in the sense of Kleitman to refer to the 24-hour cycle of day and night.

day, or lay at the most 10% under. When it came to continuous night work, on the other hand, the nightly production fell distinctly below that for day-time work. The results for men were about the same. The Health of Munition Workers Committee used as a criterion the total production per shift.

The Industrial Fatigue Research Board tried to get an idea of the variation in production from hour to hour during day and night shifts. The most extensive investigations in this connexion were done by Vernon with workers in steel mills. But these investigations did not reveal any difference between day and night work, either as regards work requiring a large amount of physical effort or light supervisory work.

Vernon also studied the accident rate at different hours of the day and night in two large series. His figures showed a lower frequency of accidents during the night than during the day. Discussing his results as regards accident rate and production at different hours, Vernon came to the conclusion that both were dependent upon many other factors than fatigue and therefore could not be taken as indicators of the degree of fatigue.

After the discouraging results of these large investigations, nothing more was done in this field. It is only recently that the problem has been taken up again. Other angles of approach are now being tried.

Browne (1949), studying telephone operators, calculated the influence of the hour on the length of time taken to answer incoming calls. He found that, on the average, the longest reaction time occurred between 3 and 4 a.m. This was true even when there were more than 80 calls per hour, showing that the long reaction time was not due to the operator dozing between calls.

Menzel (1950) examined the frequency of accidents for which a penalty was inflicted in a group of railway employees working in three shifts beginning at 6 a.m., 2 p.m., and 10 p.m. He found that the frequency was greatest between 10 p.m. and 2 a.m.

When it is desired to study diurnal variations in mental performance in industrial work, great difficulties are encountered. The greatest of these lies in the fact that the working conditions are generally not the same during the night as during the day. Efficiency is also influenced by a series of other factors, as, for example, setting of a piece rate, which could easily conceal a diurnal variation in mental performance. Large series are needed in order to eliminate chance variation.

The investigations of night and shift work described in the present article were done in 1946. We tried to avoid the sources of error just spoken of when choosing study material. Preliminary reports were presented in 1948, 1949, and 1953 (Bjerner, Holm, and Swensson, 1948; Bjerner, 1949; Bjerner and Swensson, 1953).

Present Series

The bulk of the material comes from a large gasworks (I) in southern Sweden. The subjects were men whose work it was to enter figures in columns in ledgers. Some of the figures were taken directly from meters and some were the results of computation. The first type was taken from the instruments which registered the consumption of gas, amount of gas in the gas tanks, gas pressure, temperature, height of the barometer, and other conditions. The figures calculated were those for the amount of gas produced and consumed. They were obtained by additions and subtractions of numbers, generally three or four digits in length. They were entered every hour during the day and night, and it took an experienced person 10 to 15 minutes to put them all down.

Every morning at six o'clock the figures were gone through and any errors in calculation or notation were corrected. We are convinced after our visit to the gasworks that all the figures were strictly checked.

The men worked in shifts of eight hours each, beginning at 6 a.m., 2 p.m., and 10 p.m. Shifts were changed every week. The working team was usually made up of three men. After 1920 the men got a free day each week, and a substitute was obtained for these days.

We examined the ledgers filled in between 1901 and 1943. We made an analysis of the errors in the figures, both the errors in noting the readings from the instruments and in calculation. The figures were entered in pencil. Mistakes were corrected in one of two ways. Sometimes the wrong number was rubbed out and the right one substituted. Other times the wrong number was crossed out and the right one written above it. The paper had a shiny surface and when it was held so that the light fell obliquely on it, it was easy to detect the erasures. We paid no attention to the manner of correction. Mistakes in two or more digits of one number were counted as one error only. Errors in different columns were counted separately, even when made in the same entry.

The ledgers were gone through and all the errors ticked off. Then the different errors were transferred to different tables of distribution. The tables were compiled in a way that made it possible to calculate how the errors were distributed throughout the day and night, week, month, and year. In

TABLE 1

FREQUENCY OF ALL ENTRIES WITH ERRORS DISTRIBUTED ACCORDING TO TIME OF DAY AND NIGHT

Hour	Observations with Errors (Number of Errors)															Total No. of Errors
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
06	2,134	339	60	11	2	—	3	—	2	1	1	1	—	—	—	564
07	2,173	318	49	9	2	1	1	—	—	1	—	—	—	—	—	471
08	2,209	290	47	7	—	1	—	—	—	—	—	—	—	—	—	410
09	2,184	318	36	6	4	3	1	2	—	—	—	—	—	—	—	459
10	2,149	334	55	9	6	—	—	1	—	—	—	—	—	—	—	502
11	2,172	298	61	16	3	3	—	1	—	—	—	—	—	—	—	502
12	2,098	364	68	21	2	—	1	—	—	—	—	—	—	—	—	577
13	2,177	313	41	15	1	3	2	1	—	1	—	—	—	—	—	487
14	2,100	373	64	12	2	—	—	1	2	—	—	—	—	—	—	568
15	2,127	333	73	17	2	—	—	1	1	—	—	—	—	—	—	553
16	2,145	339	57	7	4	1	—	—	1	—	—	—	—	—	—	503
17	2,137	348	53	13	1	—	1	—	—	—	1	—	—	—	—	513
18	2,130	355	55	8	2	2	—	1	—	—	—	1	—	—	—	525
19	2,165	318	56	11	2	1	—	—	1	—	—	—	—	—	—	484
20	2,186	296	52	14	3	1	1	—	—	—	1	—	—	—	—	475
21	2,120	353	58	12	5	1	—	2	—	—	—	2	1	—	—	578
22	2,121	350	65	13	1	1	—	—	2	—	—	1	—	—	—	555
23	2,099	362	58	24	4	2	2	2	—	—	—	—	—	1	—	615
24	2,083	367	74	17	7	4	—	1	1	—	—	—	—	—	—	629
01	1,997	421	89	31	10	2	1	1	1	—	—	1	—	—	—	774
02	1,931	483	97	27	9	4	2	—	1	—	—	—	—	—	—	834
03	1,795	563	147	29	12	2	—	—	5	—	—	—	—	—	1	1,056
04	1,878	517	110	32	9	3	1	—	1	1	1	—	—	1	—	930
05	2,006	416	108	17	3	2	1	—	—	—	—	—	—	—	1	725
Totals	50,316	8,768	1,633	378	96	37	17	14	18	4	4	6	1	2	2	14,289

Total observations: 61,296; Mean number of errors per observation = 0·2331 (S.D. = 0·36880)

addition, separate calculations were made for the errors made in copying down from the instruments and the errors in figures based on calculation.

It was possible to distinguish the handwriting of several different workers, and so to study the distribution of errors for separate men. The results of three of the workers, called A, C, and D, were analysed in detail.

For the final investigation the years 1912 to 1931 were chosen. The ledgers for these years were in excellent condition and no pages had to be discarded. Apart from the work already done for the preliminary investigation, the ticking off and tabulation of this material was all done by one person. This person was not acquainted with the results of the preliminary investigation.

In order to check the results, similar investigations on a smaller scale were carried out at another gasworks (II) and at a paper mill.

Results of Preliminary Investigation

The ledgers for the years studied showed that 14,289 errors were committed in 61,296 entries. Table 1 shows the distribution of the single and multiple errors in the 24 hours of the day and night. As seen there, there were many entries containing several mistakes. Analysis revealed that many of the multiple errors occurred in the columns for the pressure in the different gas-tanks. Study at the gasworks showed that in certain situations all the pressure meters changed figures at the same time. If this happened when a man was reading off the figures, he had to rub out the whole series of figures he had just written. Because of this, these columns were excluded as errors from the analysis.

The results when this was done are seen in Table 2.

TABLE 2

FREQUENCY OF ENTRIES (EXCLUDING THOSE WITH PRESSURE METER CHANGES) WITH ERRORS DISTRIBUTED ACCORDING TO TIME OF DAY AND NIGHT

Hour	Observations with Errors							Total No. of Errors
	0	1	2	3	4	5	6	
06	2,297	236	19	1	1	—	—	281
07	2,359	178	13	3	1	—	—	217
08	2,358	184	10	2	—	—	—	210
09	2,373	169	11	1	—	—	—	194
10	2,364	174	12	4	—	—	—	210
11	2,381	156	14	2	1	—	—	194
12	2,357	181	14	1	1	—	—	216
13	2,366	172	16	—	—	—	—	204
14	2,315	208	28	—	2	—	1	278
15	2,348	185	16	3	1	1	—	235
16	2,364	173	15	2	—	—	—	209
17	2,345	189	16	4	—	—	—	233
18	2,351	182	21	—	—	—	—	224
19	2,362	175	12	5	—	—	—	214
20	2,394	146	11	3	—	—	—	177
21	2,372	162	19	1	—	—	—	203
22	2,325	197	28	4	—	—	—	265
23	2,332	193	25	3	1	—	—	256
24	2,349	181	19	4	1	—	—	235
01	2,256	251	39	7	1	—	—	354
02	2,240	267	38	9	—	—	—	370
03	2,135	352	62	5	—	—	—	491
04	2,158	341	50	4	1	—	—	457
05	2,240	276	33	4	1	—	—	358
Totals	55,741	4,928	541	72	12	1	1	6,285

Mean no. of errors per observation = 0·1025 (S.D. = 0·1199)

TABLE 3

DISTRIBUTIONS ON DAYS OF THE WEEK OF ENTRIES WITH ERRORS

No. of Errors	Frequency Observed	Frequency Calculated According to:		Frequency Observed	Frequency Calculated According to:	
		Poisson	Greenwood-Yule		Poisson	Greenwood-Yule
Mondays				*Tuesdays*		
0	7931	7847·5	7933·2	7961	7926·4	7963·3
1	731	863·2	725·9	702	792·6	698·7
2	83	47·5	87·7	86	39·6	85·0
3	13	1·7	11·4	10	1·3	11·3
4	2	0·1	1·5	0	0·1	1·6
5	—	—	—	0	—	0·2
6	—	—	—	1	—	—
Total	8760	—	—	8760	—	—
n	—	1	1	—	1	1
χ^2	—	50·18	0·61	—	86·87	0·37
P	—	<0·001	0·43	—	<0·001	0·54
P_N	—	—	0·89	—	—	0·95
Wednesdays				*Thursdays*		
0	8033	7948·1	8035·1	7858	7826·0	7857·4
1	679	794·8	669·5	785	860·9	788·6
2	58	48·5	69·9	84	47·4	80·8
3	14	1·3	9·5	7	1·7	8·3
4	—	—	—	1	0·05	0·9
Total	8784	—	—	8736	—	—
n	—	1	1	—	1	1
χ^2	—	27·53	4·29	—	44·31	0·32
P	—	<0·001	0·04	—	<0·001	0·57
P_N	—	—	0·24	—	—	0·95
Fridays				*Saturdays*		
0	7982	7962·2	7981·41	7979	7869·0	7984·6
1	659	716·5	660·89	703	865·6	687·0
2	65	32·2	62·80	81	47·6	94·8
3	5	1·0	6·22	16	1·8	14·7
4	1	—	0·63	5	—	2·4
Total	8712	—	—	8784	—	—
n	—	1	1	—	1	1
χ^2	—	47·34	0·20	—	88·11	3·03
P	—	<0·001	0·65	—	<0·001	0·08
P_N	—	—	0·98	—	—	0·40
Sundays						
0	7995	7926·38	7993·76			
1	671	792·64	672·25			
2	83	39·63	81·41			
3	7	1·32	10·86			
4	3	0·03	1·52			
5	1	0·0008	0·22			
Total	8760	—	—			
n	—	1	2			
χ^2	—	70·97	0·23			
P	—	<0·001	0·63			
P_N	—	—	0·97			

Distributions fitted to the Poisson and the Greenwood-Yule curve. n = degrees of freedom; P_N = probability calculated according to Newbold.

The errors are not distributed according to Poisson but the distribution tallies fairly well with the curve constructed by Greenwood and Yule (1920) for the distribution of accidents among different persons. As seen from Table 3, the distribution of certain sections of this series fits the Greenwood-Yule curve remarkably well for each day of the week —much better than the distributions noted in the studies of accidents by Greenwood and Yule and by Newbold (1926).

Because of this great stability in the series we felt justified in studying the total number of errors at different times instead of the frequency of hours with and without errors.

The last column of Table 2 shows a distinct diurnal variation with a peak at 3 a.m. It is interesting that the diurnal variation is the same for errors in figures read off directly as for errors in figures that had required calculation.

Results of Main Investigation

The material, covering the years 1912 to 1931, includes about 175,000 entries. About 75,000 errors were made in the entries. The greatest number of mistakes were made during the night shift, the next greatest during the afternoon shift, and the lowest during the morning shift. The gas pressure columns are not included in these figures.

The distribution of the errors during the 24 hours is seen from the diagram in Fig. 1. The curve has two distinct peaks, one at 3 a.m. and another at 3 p.m. A distinct depression is observed between

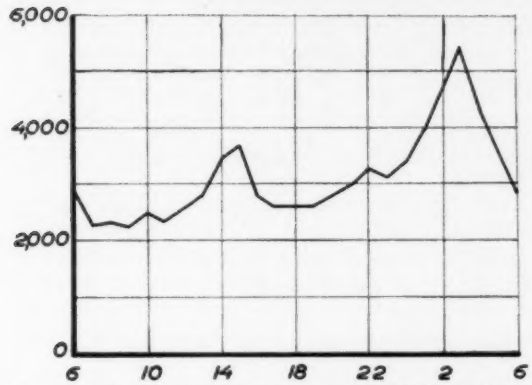

FIG. 1.—Distribution of the errors in the material from 1912 to 1931 in 24 hours of the day and night. The hour is plotted along the abscissa and the errors along the ordinate.

5 p.m. and 7 p.m. and another one, not so distinct, between 10 p.m. and 11 p.m. Comparison of the day curve from 6 a.m. to 6 p.m. with the night curve from 6 p.m. to 6 a.m. shows that the two run a similar course, but that the fluctuation is much greater in the night curve.

It is remarkable that the curve is so little influenced by the changes of shift at 6 a.m., 2 p.m., and 10 p.m.

Because of the size of the series and the regular course of the curve, it would be superfluous to make any calculations of the statistical significance.

In Table 4 the material for each year is analysed separately. It is seen there that the two peaks recur year after year. In 13 out of the 20 years the greatest number of errors, the nocturnal peak, occurred at 3 a.m., in six years at 2 a.m., and in one year at 4 a.m. The day peak was somewhat more fluctuating.

Various features of the material were analysed. The distribution of the errors made in recording the height of the barometer showed two peaks at 3 a.m. and 3 p.m. This is worthy of note, because the atmospheric pressure is not influenced by changes in the production and consumption of gas.

As already mentioned, by studying the handwriting we were able to follow the different persons who wrote in the ledgers. During the years in question, three persons, A, C, and D, were responsible for most of the records. The errors made by these persons are further analysed in Fig. 2. There the material is divided into two parts, the material from the years 1915 to 1919 and the material from the years 1920 to 1924. All three persons showed a distinct nocturnal peak in both the periods. The highest peaks occurred between 1 and 4 a.m. in all six curves.

These two periods were chosen to see whether the change from the 56- to the 48-hour week in 1919-20 had any effect on the number of errors. Fig. 2 shows that all three persons made fewer mistakes after their working hours were shortened. The reduction was not due to the shorter working time *per se*. This is seen from Table 4 which shows the total number of mistakes per year for each hour. Table 4 shows a steady reduction in the number of errors per year. This reduction stopped in about 1920 to 1922, when the curve first ran a horizontal course, and then showed a tendency to rise. Examination of the curve in Fig. 2 shows that it runs about the same course before and after the reduction of the working day. Subject D has a more distinct nocturnal peak before the reduction.

TABLE 4

YEARLY DISTRIBUTION OF ERRORS ACCORDING TO TIME OF DAY AND NIGHT

Time	1912	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	Total Sum
06	345	172	186	197	203	110	127	179	80	105	104	53	49	101	161	122	131	173	149	117	2·864
07	212	129	178	166	143	100	94	124	66	72	67	59	55	60	149	93	93	125	157	115	2·257
08	245	171	183	145	136	82	89	141	64	73	88	76	53	80	113	92	81	138	130	137	2·317
09	217	108	138	172	128	81	65	109	56	67	65	65	64	74	123	124	95	156	152	133	2·192
10	221	141	147	176	175	70	97	137	65	93	47	97	63	90	156	132	129	161	148	154	2·499
11	191	124	145	136	118	91	94	146	52	70	76	75	88	111	141	150	122	127	142	129	2·328
12	210	133	174	142	165	98	89	136	78	87	89	98	95	120	157	135	143	156	161	163	2·629
13	260	155	160	196	174	85	109	116	77	96	69	127	89	147	180	165	135	172	163	164	2·839
14	332	180	178	*217*	*184*	112	125	123	103	*139*	*105*	*184*	95	*203*	*239*	*213*	191	180	200	180	3·483
15	*415*	*245*	*224*	215	182	*164*	*126*	*158*	103	124	101	171	65	141	209	182	*228*	*220*	*223*	*190*	*3·686*
16	242	136	177	150	144	123	93	135	99	92	72	137	88	109	151	164	176	174	195	138	2·795
17	197	131	164	125	178	132	113	134	79	77	80	110	*114*	128	151	137	140	149	135	159	2·633
18	186	151	163	150	139	127	116	153	91	105	84	122	92	115	148	148	144	156	156	132	2·678
19	212	148	179	146	130	129	88	149	112	72	87	113	89	146	145	150	145	149	160	136	2·685
20	209	141	183	150	142	101	112	148	91	91	84	110	80	130	167	150	173	150	175	140	2·727
21	227	196	187	166	180	135	114	155	108	92	86	118	80	119	167	175	174	221	181	129	3·010
22	313	175	194	204	148	132	143	171	84	149	115	143	96	132	214	181	172	202	173	153	3·294
23	273	202	221	178	162	142	143	198	95	113	96	110	87	126	138	190	148	177	187	156	3·142
24	267	171	217	199	207	167	155	192	101	122	114	140	105	125	184	177	185	207	211	180	3·426
01	382	190	279	254	193	143	181	252	143	132	128	156	130	138	193	202	221	247	256	179	3·999
02	433	214	268	293	248	*196*	238	247	*188*	*187*	158	221	*166*	*218*	260	224	262	250	277	*231*	4·779
03	*582*	*246*	*359*	*308*	280	182	*309*	*354*	183	159	*202*	*299*	131	199	*313*	*276*	*292*	*252*	*289*	221	*5·436*
04	394	222	315	261	*285*	167	295	268	142	133	192	213	103	156	209	197	200	198	235	156	4·341
05	256	157	238	156	190	187	135	210	79	47	124	132	117	125	130	118	141	154	109	83	2·888
S : a	6,821	4,038	4,857	4,502	4,234	3,076	3,250	4,145	2,339	2,477	2,433	3,129	2,194	3,093	4,198	3,897	3,921	4,294	4,364	3,675	74,927

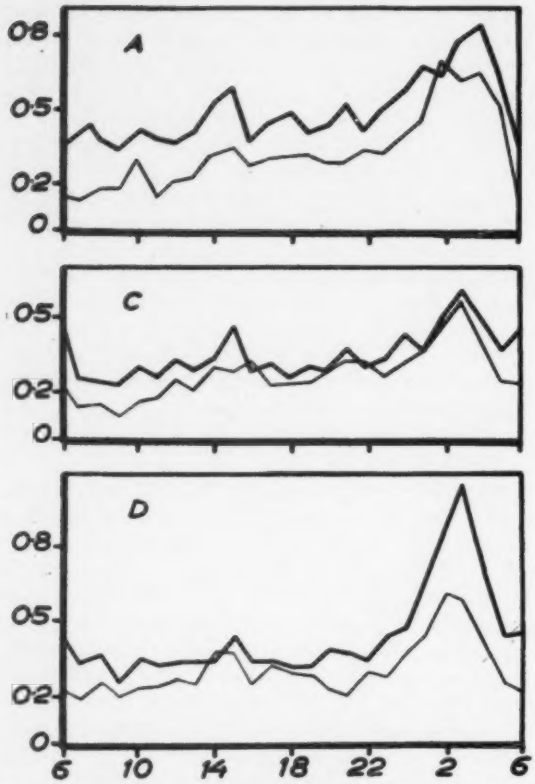

FIG. 2.—Distribution of errors made by each of three employees (A, C, and D) at a gasworks.

The bold curve is for the years 1915 to 1919 (56-hour week), and the light curve for 1920 to 1924 (48-hour week).

The hour is plotted along the abscissa and the number of errors per shift along the ordinate.

As yet we have neglected the question of whether the propensity to error varies during the course of a night-shift week. To examine this question, we took the years 1915 to 1919 and compared the first three and the last three of the seven successive night shifts done at that time. Fig. 3 shows that all three persons evidenced remarkably little difference in performance during the first and second halves of the week. After the shortening of the working week in 1920, different types of shift were tried. During the years 1922 to 1926 a free day was inserted between the first three and the last three nights of a week of night work. It is interesting to see whether this had any influence on the high frequency of errors during the night shift. As seen from Fig. 3, there was no essential difference in the course of the curve during the first and last nights of a night-shift week. The shortening of the working hours did not have any distinct influence on these curves. Nor did the figures for the separate persons show any systematic change in the fluctuation during the course of a night-shift week.

The curves for the winter months November to January and for the summer months May to July were compared for each of the three persons. As no difference was noted, the figures are not considered here.

The figures from another gasworks and from the electrical control room of a paper mill are shown in Table 5. As seen there, both these series showed the same peaks in errors at the same times of the day and night. The figures from the gasworks are taken from the ledgers for 1944, 1945, and 1947.

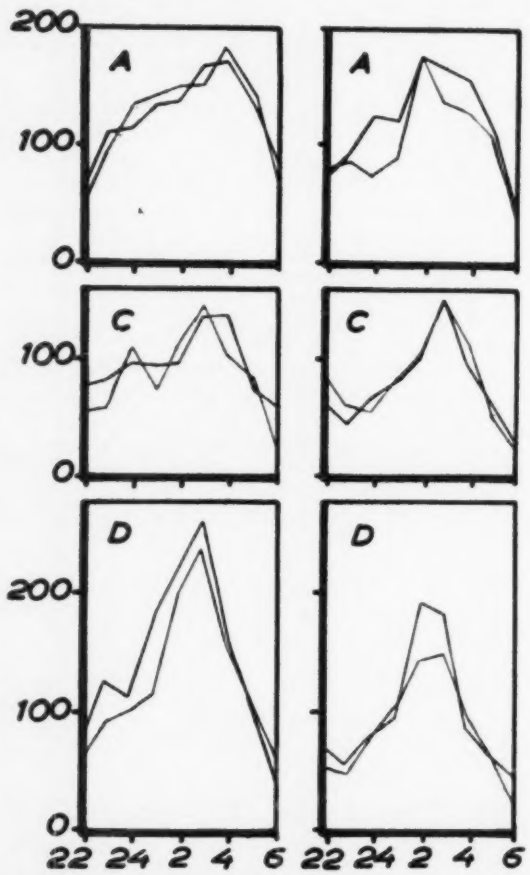

FIG. 3.—Distribution throughout night-shift week of errors made by three employees (A, C, and D) at a gasworks.

The columns on the left cover the years 1915 to 1919, during which period the men worked seven night shifts in succession. The columns on the right cover the years 1922 to 1926, during which a free day was inserted between the first three and the last three nights of a night-shift week.

The bold curve shows the first three nights of night-shift weeks, the fine curve the last three nights of night-shift weeks.

The hour is plotted along the abscissa and the errors along the ordinate.

TABLE 5

NUMBER OF ERRORS DISTRIBUTED ACCORDING TO TIME OF DAY AND NIGHT AT GASWORKS I, GASWORKS II, AND PAPER MILL

Hour	Gasworks I		Gasworks II	Paper Mill
	Registration of Barometer Height	Sum of Errors from Table 4		
06	23	2·864	147	82
07	83	2·257	204	40
08	84	2·317	229	37
09	68	2·192	243	41
10	83	2·499	231	52
11	73	2·328	241	57
12	99	2·629	249	66
13	86	2·839	240	56
14	127	3·483	297	86
15	*139*	*3·686*	*326*	*120*
16	92	2·795	283	106
17	109	2·633	308	98
18	105	2·678	271	98
19	91	2·685	278	80
20	98	2·727	290	86
21	108	3·010	258	95
22	114	3·294	390	108
23	107	3·142	331	107
24	105	3·426	393	102
01	102	3·999	418	116
02	121	4·779	413	100
03	*162*	*5·436*	*559*	*133*
04	113	4·341	441	116
05	58	2·888	377	96

They cover about 26,300 entries containing 7,417 errors. The figures for the paper mill are taken from the year 1945 and cover about 8,800 entries containing 2,078 errors.

Discussion

The results reported here are based on a particular performance repeated every hour of the day and night for several years. The performance consists of making note of the figures given on certain instruments and recording some of them directly in ledgers and others after calculation. The errors made in this test were undoubtedly caused by many things. It may be assumed that variations in quality of mental performance is one of them. As seen from the results, the frequency of error fluctuates in a remarkably regular manner throughout the day and night. Several sources of error, however, must be considered. The fluctuations may be due to changes in the kind of work. They may be due to cyclic changes in the environment, for example, in temperature or degree of illumination. All these sources of error must be eliminated before it is possible to refer the variation in errors to variations within the person.

The work dealt with in this study is of practically the same nature throughout the 24 hours. It is conceivable, of course, that the test becomes more difficult when there is a large consumption of gas, inasmuch as the figures fluctuate more, making the calculation a little more difficult. But this would not explain the curve here, for the gas consumption is least during the night. Any doubt as to this is dispelled by the fact that the diurnal curve for errors in noting the height of the barometer runs the same course.

The question arises whether the variation between light and darkness during day and night might be influential. During the winter months November to January it is dark during the whole night shift. During the summer months May to July it is light for the greater part of this shift. This did not cause any difference in the course of the nocturnal curve. Furthermore, it is darkest at midnight but the errors showed a distinct peak at 3 a.m.

Since no fluctuations in the environment can be found to explain the diurnal fluctuation in errors, it must be assumed that the latter is due to variation in the individual in question, to variation in his capacity for mental performance. It is reasonable to assume that the curve reflects the degree of wakefulness during the day and night. The fact that the same type of variation is shown year after year by different persons and is seen in different series shows that the degree of wakefulness fluctuates in a highly consistent fashion during the 24 hours of the day and night. The large increase of errors during the night corresponds well with the feeling we all have of being more tired at night than during the day, something which is particularly noticeable during nocturnal vigils. Persons doing the type of night work described in this study often say that they are sometimes so tired between 2 and 3 a.m. that they fall asleep when they are supposed to write. Menzel (1950) made systematic inquiries of 210 shift workers with the same times for changing shift as our subjects. The answers to the inquiry as to the most difficult time of the night to work distributed themselves in a Gaussian curve with a peak at 3 a.m. This agrees with our results.

Because of the large number of observations, the degree of fatigue at each point being "tested" about 7,000 times, the results are convincing, at least as regards the subjects in question. This is especially true in view of the fact that a series from another gasworks and a paper mill gave the same result. It must be remembered, however, that the subjects were few in number, the bulk of the material in the main study being furnished by three persons. Furthermore, these persons had a monotonous scheme of work, with a change of shift at 6 a.m., 2 p.m., and 10 p.m. This is also true of the other two series. It is possible and even probable that persons with other habits of living and other hours of work would show another diurnal curve. It would be very interesting to compare our results

with those of studies of groups with other working hours. We have searched a great deal but have not been able to find suitable material for comparison.

As mentioned earlier, a series of biological processes has been found to vary according to a diurnal rhythm. As the situation is now, it is idle to speculate on which of these rhythms are primary and which are secondary.

The practical significance of this fluctuation in mental performance is obvious as regards industrial workers, transport employees, and the like. It seems that one cannot expect a person to have the same capacity during the night as during the day. It is interesting to note that the shortening of daily hours of work in 1920 did not have a great influence on the diurnal variation. It is likewise interesting that the fluctuation seems to follow the same curve during the last three nights of a night shift as during the first three. It seems as though seven days were not enough for the organism to adapt itself to night work. Holmgren and Swensson showed that animals needed about a week to adjust themselves to a change in diurnal schedule. This in no way contradicts our observation, however, for their experimental animals and our human subjects were faced with quite different situations. The animals only had to adjust their activity to the new order in their society. The man changing to a night shift, however, has to change his personal routine to one which is quite different from his fellow men, who go on living in the same old way.

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PHYSIOLOGICAL OBSERVATIONS ON MEN WORKING IN SUPPOSEDLY LIMITING ENVIRONMENTS IN A WEST AFRICAN GOLD-MINE

BY

W. S. S. LADELL

From the Hot Climate Physiological Research Unit, Oshodi, Lagos, Nigeria

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In recent years there has been renewed interest in the problem of "limiting environments" (Eichna, Ashe, Bean, and Shelley, 1945; Adolph, 1946). The appreciation that the body temperature may safely be allowed to rise a few degrees above the "little arrow on the thermometer" (Du Bois, 1948) has meant that the wet-bulb limit of 88° F., suggested by Haldane's work (1905), has long since been discarded. Almost any environment may be tolerated and even worked in for a short time; thus Blockley and Taylor (1949) found that men at rest could tolerate a temperature of 240° F. for 20 minutes when the air was dry. Craig, Garren, Frankel, and Blevins (1954) consider the determining factor in voluntary heat tolerance is total heat storage, the best single estimate of which, they suggest, is the rectal temperature. In their tests the mean final rectal temperature at which the men gave up was 102° F. (S.D. 0·54). For exposures lasting several hours Robinson, Turrell, and Gerking (1945) have evolved a complex index of physiological stress, in which changes in skin temperature, sweat rate, rectal temperature, and heart rate are all taken into consideration. The M.R.C. Climatic Unit (1947), led by McArdle, after a long series of tests concluded that a single physiological observation, the sweat rate, was sufficient to indicate the severity of a heat stress, and from their results a nomogram was constructed from which, given the relevant figures, the sweat production for a four-hour exposure could be predicted (predicted four-hour sweat rate or P4SR). From their observations on hyper-acclimatized subjects they concluded that the threshold for intolerance was reached when the P4SR was 4·5 litres. Recent work on the same lines reported by Ellis, Ferres, Lind, and Newling (1954) in Singapore has shown that the limit suggested by McArdle was substantially correct. In Fig. 1 the London and Singapore limits for men in overalls and those suggested by Robinson and others (1945) are plotted together; all three groups of workers also set the upper limit of tolerance for men dressed in shorts working at 2 to 2½ met. (1 met. = 50 kg. cal./sq. m./hr.) at about the same area on the psychrometric chart.

Working conditions which approach these tolerance limits have been described several times in mines; for example, by Weiner (1950), who found working temperatures in Rand mines of 93·7° F. dry-bulb, 92·7° F. wet-bulb, and Caplan (1944) who reported working places in Indian mines with a dry-bulb temperature of 112° F. and a wet-bulb one of 96° F. In both places collapse from heat occurs, but it does not seem to be a major problem until even higher temperatures are reached. On the other hand the amount of useful work that can be done is severely limited under such conditions; Caplan and Lindsay (1946) found that only about one hour's good work was possible when the wet bulb reached 93° F. or the effective temperature 96° F.; this corresponds to the "50% failure line" determined by Ellis and others (1954).

In a Nigerian colliery, where conditions were uncomfortable rather than severe, the workers avoided heat stress by taking frequent rests and by taking time off in cooler, well-ventilated roadways whenever they could (Ladell, 1948b). Conditions in West African gold-mines are more severe than in the colliery, and through the courtesy of the Ashanti Goldfields Corporation the physiological observations reported here were made on the workers in one of their deep mines at Obuasi. These observations show how the West African miners react in situations where conditions are near the accepted tolerance limit.

From the ventilation reports the stope temperatures in this mine varied from 82 to 97° F. and the wet-bulb temperatures from 81·5 to 96° F. The

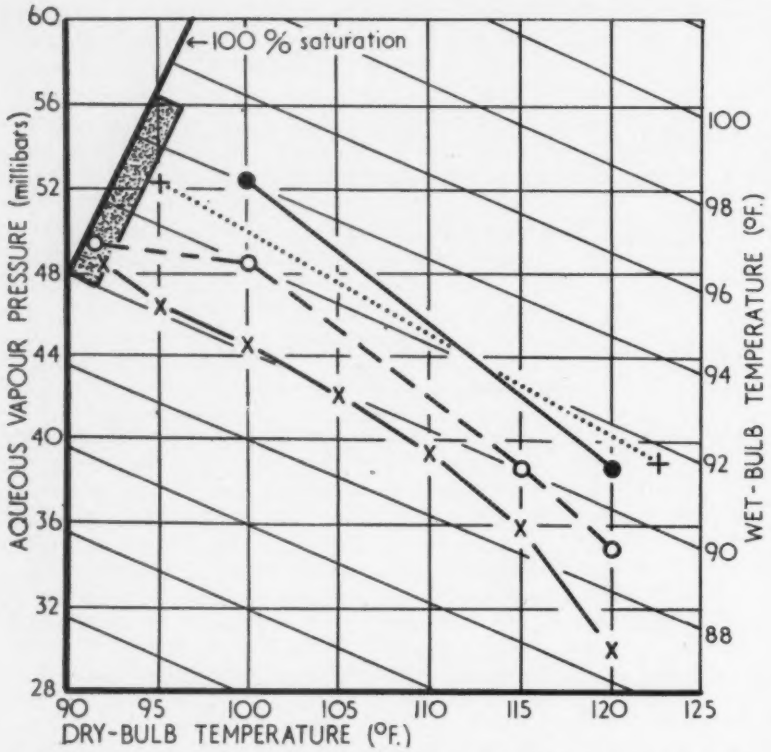

FIG. 1.—A portion of a psychrometric chart showing the tolerance limits reported by various authors.

(1) *Men in overalls working at 2·0 met.* (Ellis and others, 1954). Spots with solid line = more than 50% failure. Circles with broken line = upper limit for no failure.

(2) *Men in overalls working at 2·0 met.* (M.R.C., 1947). Crosses with solid line = predicted upper limit of tolerance for fit acclimatized young men. (P4SR = 4·5 1.)

(3) *Men in shorts working at 2·6 met.* (Robinson and others, 1945). Crosses with dotted line = upper limit for thermal equilibrium.

The stippled area covers the conditions found in the working places.

mean mine temperature for the month preceding the one in which this investigation was made was dry-bulb 90·5° F., wet-bulb 89·5°F., relative humidity 96%. In 60 out of 126 stopes the dry-bulb temperature was 92° F. and over, with humidities above 90%. Conditions were therefore generally approaching the "50% failure line" for men working at 2 met. even in moving air, but the medical records of the mine showed that breakdown due to heat was quite unknown. On a preliminary tour of the mine, temperatures up to 95° F., with a wet-bulb temperature of 94° F., were encountered; in no working place was there enough movement of the air to be measured with the vane anemometer and casual observations of rectal temperatures on machine and blast "boys" revealed temperatures of 102° F. and higher. This suggested that serial observations on the body temperatures of men working in hot districts would be of value as, when men are working at a variable rate, body temperature is the most reliable index of body heat-stress; the heart rate, for example, is too much affected by alterations in activity.

Temperature and Body-weight Changes in an Eight-hour Shift

As many men as possible working in two adjacent hot districts (29 South 10 and 30 South 6, referred to hereafter as districts A and B respectively) were assembled on the surface before the morning shift, their rectal temperatures were taken, and they were weighed stripped. They were then followed down the mine to their work places and thereafter their temperatures were taken at intervals of one to two and a half hours for the rest of the shift, with the minimum of interference with their work; the men were then followed to the surface, a final temperature taken, and they were weighed again. The time of each observation underground was noted; the first was taken 80 min. after beginning the surface observations and the last at the station at the bottom of the shaft waiting to come up, 450 min. afterwards. Initially cooperation was poor, and only 26 men could be observed on the surface before the shift of whom 24 were traced underground; but a further 19 men volunteered underground and 34 men reported for the final surface observations, of whom 22 were from the initial group. In all, 147 observations were made underground on 26 men working at the stope wall in district A, on eight stope workers from district B, and on 11 truck men. No records could be kept of water drunk or urine passed underground.

Temperatures and humidities underground were observed frequently, using a sling psychrometer, and the air movement was determined as each batch of observations was being made, using a high temperature (130° to 135° F.) silvered katathermometer. Conditions in district A were: dry-bulb

93 to 93·5° F., wet-bulb 92 to 92·5° F., air movement 60 to 70 ft./min., basic effective temperature 91·5° F.; and in district B : dry-bulb is 95·5° F., wet-bulb 93·5° F., air movement 80 to 90 ft./min., basic effective temperature 93° F. There was therefore little difference between the two districts, but the men in B had access to a side-tie where the air movement was 470 ft./min. In the roads where the truck men spent most of their time either bringing in the empty bins or taking away the full ones the dry-bulb temperature was only 86° F. and the wet-bulb temperature 85° F. These men made their own air movement as they walked, estimated as at least 200 ft./min.

Results

Overall Changes : (a) Rectal Temperatures.—The mean rise in rectal temperature of 17 men from the stopes was 1·5 ± S.E. 0·15° F. ; the greatest rise was 2·7° F. in a shovel man and the smallest was 0·3° F. in a timber man. The highest post-shift temperature observed was 101·3° F. in a wall man whose initial temperature had not been taken. The mean rise in five truck men was also 1·5° F. In view of the low initial temperatures of these men, 10 of whom out of 26 had initial temperatures of 98·5° F. or lower, this rise does not indicate any overall pronounced stress, but these men all had an opportunity to cool off at the station (shaft bottom) before coming to the surface and many of them had bathed in the cool drainage water ; the mean fall in temperature of 15 men between station and surface was 0·5 ± S.E. 0·13° F.

Overall Changes : (b) Weight Losses.—The mean weight loss of 22 men during the eight-hour shift was 1·5 kg. ± S.E. 0·145, ranging from 0·2 to 2·8 kg. The shovel men had losses above the average but otherwise there was no indication that one type of worker lost more than another. Overall sweat losses could not be calculated as no record could be kept of fluid intake or output ; the recorded weight losses therefore represent voluntary dehydration (Adolph, 1947). These are considerably lower than those recorded by Moss (1923) for men in a hot British colliery, where weight losses varied from 4 to 8 kg. in a five-hour shift.

Temperature Changes During the Shift.—Rectal temperature observations numbered 123 on men in the stopes and 24 on truck men in the roads. Temperatures of 100° F. and higher were recorded from men within one and a half hours of their going underground, representing a rise of 1·3° F. from the mean temperatures recorded on the surface.

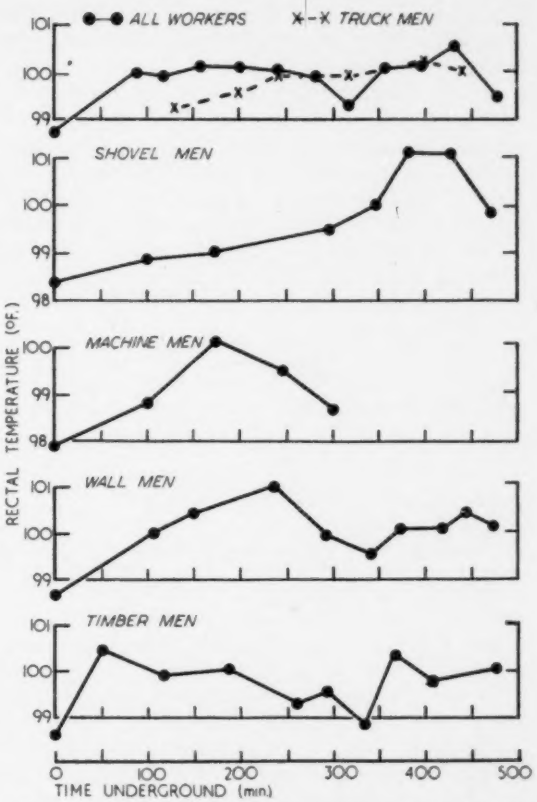

FIG. 2.—Pattern of rectal temperature changes during the shift according to occupation underground.

In the middle of the shift there was a lull in the rise of temperature and in some cases an actual fall, so that more temperatures of 99·5° F. and lower were seen at this time than earlier in the shift ; subsequently temperatures began to rise again and the mean temperature of 17 men at the station about to go off the shift was 100·64° F., representing a rise of 1·9° F. Seven out of 34 men from the stopes reached a temperature of 101° F. in the first half of the shift and a further seven in the second half ; only one truck man reached this temperature and then only after five and a half hours.

The contrasting reactions of the truck workers, who had a steady task for the whole shift carried out for most of the time in the cooler, well-ventilated roads, and of the stope workers, whose tasks, though intermittent, were carried out in hot, unventilated dead-ends, are shown in Fig. 2 ; this figure shows the mean rectal temperatures for the groups in successive periods of the shift. The stope workers were always more heat-stressed than the truck men,

except for a short time just after the middle of the shift, when there was a lull in the temperature rise of the stope workers. The extent of this lull was shown by plotting body temperatures against time of observation and drawing a line from the mean pre-shift surface temperature (time, 0) to the mean temperature at the station (time, 450 min.). The number of observations falling above and below this line in each of the three periods, (*a*) 0 to 200 min., (*b*) 201 to 350 min., and (*c*) 351 to 450 min., are shown in Table 1.

TABLE 1

DISTRIBUTION OF INDIVIDUAL RECTAL TEMPERATURE READINGS ABOVE AND BELOW THE LINE JOINING INITIAL AND FINAL MEANS IN STOPE WORKERS ONLY

	Period		
	0–200 min.	201–350 min.	351–450 min.
Values above line ..	30	14	17
Values below line ..	16	25	22

χ^2 for this distribution is 8·025, for which P is less than 0·02. The body temperatures of the stope workers were therefore distributed with respect to time in a way significantly different from that expected on the hypothesis that there was a steady rise throughout the shift. More high temperatures than would have been expected occurred in period (*a*) and more low ones in period (*b*). This is suggestive of an initial period of heavy work, followed by a rest during which the temperatures fell. There is a more even distribution in the third part of the shift, indicating a steady rate for this last period.

This pattern of work was especially marked among the wall men and the timber men, but was not shown by the machine- or shovel-men (see Fig. 2); the mean mid-shift drop in eight wall men on whom a sufficient number of observations were made was 1·04 ± S.E. 0·19° F. Only the timber men showed the pattern as a group; each man had a single maximum, either early in the shift with a subsequent falling off for the rest of the time, or else a low temperature for two-thirds of the shift and a sudden rise in the last period. The five shovel men observed showed a steady rise for the whole shift, and the five machine men each showed a maximum about three hours after going underground; later their temperatures fell to what they had been in the first hour. Rectal temperatures above 101° F. were observed in one blast man, three out of five machine men (one was above 101·5° F.), three out of five shovel men (all above 101·5° F. and two of 102° F.), four out of 12 wall men (two above 101·5° F.), and three out of 10 timber men.

No direct measurements could be made of the metabolic cost of the various tasks of the men at the face; but from observation and from interrogation the heaviest task appeared to be that of the shovel men. The metabolic cost of shovelling was therefore measured later, using three trained men in the laboratory. Rubble similar in size and density to the broken rock at the bottom of a stope wall was piled against a wall and the subject had to shovel this up from the floor and into a bin, the rim of which was 3 ft. above floor level, to represent the lip of a mine truck; the men shovelled at the rate of 1½ cubic ft./min. for six minutes and the expired air for the last four minutes was collected and analysed. The metabolic cost measured in this way was 7·28, 7·75, and 7·12 kg. cal./man/min. respectively for the three men, representing a mean excess metabolism of 0·71 kg. cal. per cubic foot of rubble shovelled. The mean overall metabolic rate was 245 kg. cal./sq. m./hr., approximately 5 met. If shovelling was equally energetic underground, and there is reason to think it was, the high rectal temperatures of some shovel men were not surprising; on the other hand, the time they took to reach such temperatures suggests that their work was somewhat intermittent. The M.R.C. team found that the rectal temperature rise (in ° F.) in four hours in " fully acclimatized fit young men " was 0·4 times the P4SR (in litres). The rises predicted in this way for the average conditions observed were: for men working at 2 met., 2·0° F. (P4SR = 5 litres) and at 4 met., 2·8° F. (P4SR = 7 litres). From the observed mean initial rectal temperatures after four hours the temperatures should have been between 100·6° and 101·4° F., depending on the work rate. Twenty-one out of the 34 stope workers observed did show temperatures in this range, some early in the shift and some considerably later, suggesting that many men began the shift at a high rate of work, probably more than 4 met. (note the high metabolic cost of shovelling), but that in the middle of the shift they slackened off and began again later after a partial recovery. This recovery was probably to be associated with the enforced break that occurred every shift during blasting, because many men spent it in the cooler, well-ventilated roads or sideties; the individual temperature patterns also suggested that some men did little work after this break and others little before.

Heat Tolerance of the Workers

Although the P4SR for men working in the conditions found in the stopes visited varied from

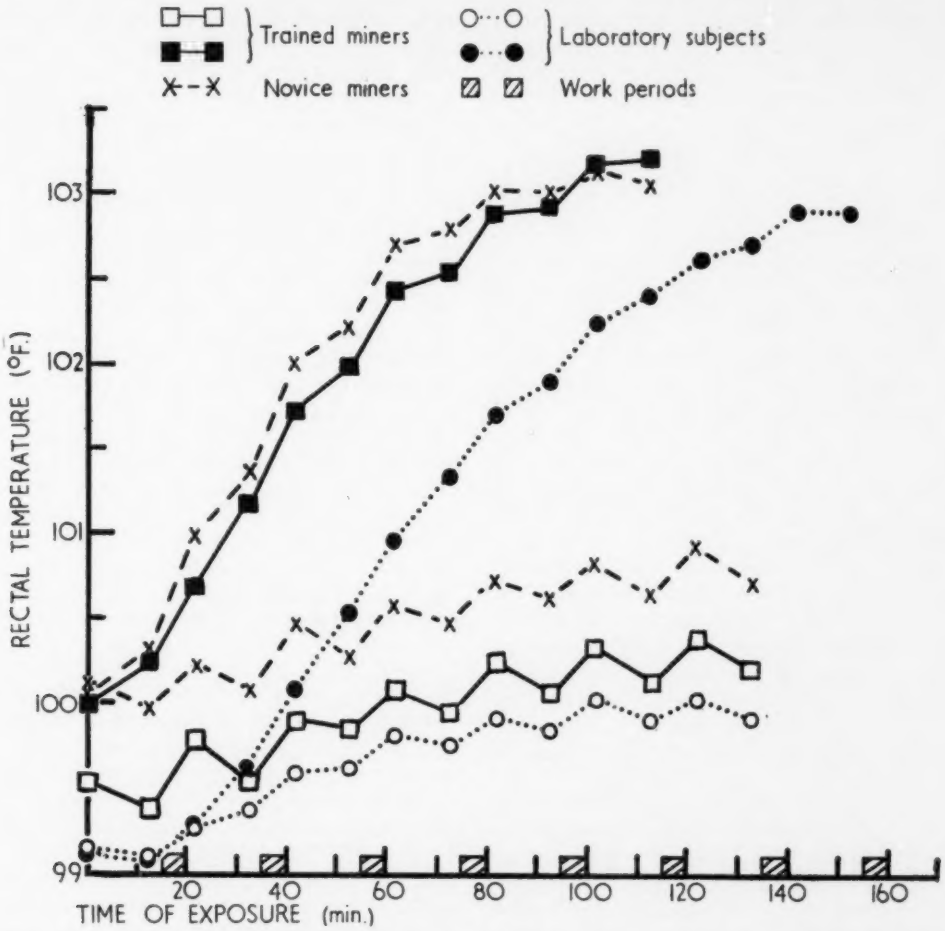

FIG. 3.—Rectal temperature changes during the standard test (*a*) at 95° F. effective temperature (upper family of curves) and (*b*) at 89° F. effective temperature (lower family of curves). The hatched blocks on the base line indicate the work periods. The mean metabolic cost of the routine was 2 met.

5 to 7 litres, depending on the assumed work rate, and it has been suggested that whenever the P4SR is above 4·5 litres some heat collapses are to be expected, none had ever been recorded here. As the men were apparently exposed to these conditions for seven hours a day (allowing one hour for getting to and from the working places) this absence of disorders due to heat was remarkable. The M.R.C. limit has been confirmed by other workers, and Fig. 1 shows that in some of the working places a high degree of failure could have been expected. Even allowing for the fact that the men escaped from the worst conditions for a time at mid-shift, it seemed that if these men were working at a full rate they must have an unusually high heat tolerance, especially as heat collapses have been reported from the Kolar gold-mines at even lower effective temperatures, namely, 103° F. dry-bulb, 83° F. wet-bulb, effective temperature 88° F. (Caplan, 1944). The heat tolerance of these workers was therefore determined by making them carry out a standard routine in two different climates, one very severe and the other less so, and comparing their reactions with those of a group of men whose heat tolerance had been already determined (Ladell, 1951). At the same time the effect of training could be determined by testing under the same conditions a group of novices newly come to the mine. The required severe climate was found in district 30. N. 3, where the dry-bulb temperature was 96° F., wet-bulb temperature 95° F., air movement 15 ft./min., basic effective temperature 95° F.; the milder

climate was found at the end of a disused road on the 30 level, where the conditions were: dry-bulb 90·3° F., wet-bulb 90·2° F., air movement 70 ft./min., basic effective temperature 89° F.

Subjects Used.—The novices used in these tests were drawn at random from the mine "school" and they compared well with the group of workers who had been seen underground, both in mean body weight and in height; the trained men tested were, however, as a group, smaller than the underground workers previously studied; as can be seen from Table 2 their mean weight and height were both statistically significantly lower, $t = 4{\cdot}01$ for weights and 3·12 for heights ($P < 0{\cdot}01$). The reason for this was that stope workers were unwilling to volunteer and the "trained men" group included undersized "sanitary" and "water" boys. Fewer heights were measured than weights as some subjects failed to report on the surface for this measurement; and some of those tested in the severe climate did not report for the less severe tests and had to be replaced by others. On the afternoon before they were tested underground the men were taken through the routine on the surface in the "cold", so they were not completely new to the test when they performed it underground.

TABLE 2

PHYSICAL MEASUREMENTS OF THE EXPERIMENTAL SUBJECTS AND MINERS INVESTIGATED

Group	Weights			Heights		
	No. Observed	Mean (kg.)	S.D. (kg.)	No. Observed	Mean (cm.)	S.D. (cm.)
Underground workers on 8-hr. shift	38*	63·1	6·76	26	176·0	7·5
Trained miners tested	14	54·7	6·67	12	168·0	7·6
Novice miners tested	14	59·2	5·35	6	174·1	7·3
Laboratory subjects	9	54·1	6·33	9	164·4	11·53

*Including 12 men weighed at end of shift only; these values corrected to "pre-shift" by adding the mean observed weight loss during the shift, 1·5 kg.

Conduct of Tests.—There was a delay of 30 to 40 min. between the subjects' reaching the bottom of the shaft and beginning the test. For about half this time they were either walking along the main road, with the temperature gradually increasing from 86° F. at the station to 90° F., always 90–100% saturated, or climbing ladders between levels to get to the test site, and for the rest of the time they were resting in the test climate while the experimental equipment was being set up.

The subjects performed a standard routine (Ladell, 1951) of successive 20-min. cycles of five min. "work" (stepping on and off a stool 12 in. high) and 15 min. sitting at rest, the mean metabolic cost of which is 2 met. The rectal temperatures and the standing heart rates of the subjects were measured before and after each work period, and the men were weighed after each cycle on a spring platform scale which could be read to the nearest 100 g. The men were naked, without shoes, but wore a sweat collecting bag on one arm which was tapped every second cycle. Drinking was encouraged and a record kept of fluid intake and output. Temperature and humidity were measured with an Assmann psychrometer and the air movement with a high temperature silvered katathermometer; globe thermometer readings were also recorded.

For comparison a group of trained, but not artificially acclimatized African subjects later carried out the same routine in the climatic chamber in which the conditions of the underground tests were simulated. The physical details of these men are shown in Table 2. These subjects were further tested at various times in other combinations of heat and humidity giving the same corrected effective temperature as those obtained during these tests.

Results

Tests at Effective Temperature 95° F.—Three groups of four novices were tested on days 1, 2, and 5, and two groups of four trained miners on days 3 and 4. The tests on day 1 were discontinued after the first 40 min. as the mean rectal temperature of the men at this time was already 102° F. and no arrangements had been made for rapid artificial cooling; on the subsequent days ice was available for this purpose and the subjects were allowed to develop temperatures up to 104° F. Variations in air movement, temperature, and humidity were negligible and the globe temperature was within 0·5° F. of the dry-bulb temperature throughout. The tests on the trained subjects in the climatic chamber were carried out on three successive days on three men a day, at a mean dry-bulb temperature of 96·1° F. and a wet-bulb one of 95·4° F. in "still" air.

Stamina.—All the trained miners, but only five of the eight novices tested on days 3 and 5, completed 112 min. (five cycles) at the full rate of work. One novice complained of giddiness after three cycles and had to go slow, and two men were stopped by the observers as their temperatures had reached 104° F. Neither the trained nor the novice workers could have continued beyond 112 min. but the laboratory team of nine men were all able to carry on for 152 min. (seven cycles) and none failed.

Rectal Temperature Changes.—The mean initial temperature for each of the groups tested in the mine was 100° F. The mean initial temperature of the laboratory subjects was 99·1° F. and they only reached 100° F. after two cycles of work and rest. This was because observations were begun and the test started in the climatic chamber as soon as the subjects entered, whereas underground observations could not begin until the men had already had some exercise and been exposed to the heat for 30 to 40 min. The mine subjects' temperatures rose throughout the tests, but the laboratory subjects showed the characteristic dip in the rectal temperature on first being exposed, before beginning to rise. The temperatures of all three groups ran parallel (see Fig. 3), but the laboratory group were approximately two cycles, or 40 min., behind the other two. The difference in mean rectal temperature between the trained workers and the novices was not statistically significant; immediately after the third work period the mean temperatures were: novices, 102·69 ± S.E. 0·23° F.; trained workers, 102·43 ± S.E. 0·21° F., $t = 0·6$. After 10 minutes' rest the respective figures were: 102·9 ± S.E. 0·19° F., 102·54 ± S.E. 0·20° F., $t = 0·8$. The corresponding figures for the laboratory group after five cycles in the climatic chamber were: after work 101·90 ± S.E. 0·20° F., and after rest 102·23° ± S.E. 0·23° F. Comparing these values with the miners' taken as one group gives $t = 2·3$ for the working values, that is, the difference is just significant, $P = 0·02$, but for the resting values $t = 1·37$, which is not significant.

The maximum rectal temperature recorded in the trained group was 103·8° F. in one man immediately after his last work period. Two novices reached 104° F., one after his third work period, and the other 104·2° F., after his fourth period. One man in the laboratory group reached 104° F.; during his sixth work period his temperature rose from 103·9 to 104·3° F. and after the seventh it rose to 104·7° F.; the next highest temperature in this group was 103·7° F.

Although thermal equilibrium was never established, subjects with very high temperatures cooled down slightly when they were not working. One of the novices cooled from 104·2 to 103·6° F. in the last cycle during which he did not work, hence the lower mean final temperature of the novices' group. Similarly in the climatic chamber the temperature of one man fell from 104·7 to 104·4° F. during his last rest period.

Pulse Rates.—In Fig. 4 the mean pulse rates for each group are plotted against the mean rectal temperatures for each successive observation; separate curves have been drawn for the "immediately post-work" and the recovery values. Although the mean pulse rates of the trained miners were slightly higher than those of the novices, this difference was not statistically significant. The pulse rates of the laboratory subjects were, however, considerably lower, the mean post-work rates here being approximately the same as the mean recovery rates of the miners. The mean pulse rates in the last two cycles of the laboratory group were compared with the corresponding means for all the miners taken as one group; $t = 4·227$ and 5·556 (P less than 0·01 in both cases) for the post-work and recovery values respectively, indicating that the differences were statistically significant. The maximum observed pulse rates were 190, 188, and 186 beats/min. in the trained men, novices, and laboratory subjects respectively. The maximum rates were not associated with the maximum temperatures, and from Fig. 4 it can be seen that little rise in pulse rate occurred after the temperature had reached 102° F. except in the case of the resting laboratory subjects; this may be an indication that limiting pulse rates were being reached.

Sweat Rates.—Owing to the limitations of the instrument used in the underground tests the serial weight losses could not be measured very accurately; the mean rate of sweat loss was therefore estimated for each of the two groups indirectly by calculating the regression of sweat loss on time, using the individual observed weight losses corrected to a mean body weight of 65 kg. (Adolph, 1947), and the formula for a regression passing through the origin. Although this was more accurate than the estimation of the overall weight losses from the initial and final weights only, it does not take into account the falling off in sweat rate that occurs in the course of a long exposure (Robinson and Gerking, 1947), the so-called sweat-gland fatigue. Fig. 5 shows that in the laboratory subjects the fall in sweat rate began after only one hour's exposure, at a time when the rectal temperature was still rising; if the miners reacted in the same way they would have reached their peak sweat rate earlier in the tests; as they were exposed to the climate before the test their initial state was probably comparable with that of the laboratory subjects between 30 and 50 min. Sweat rates, calculated from the regressions, were: for trained miners, 16·3 ml./min., and for novices, 12·1 ml./min.; the difference is statistically significant ($t = 5·67$, $P < 0·01$). The sweat rates for the laboratory subjects, corrected for a body weight of 65 kg., as estimated direct from serial weighings, were: 10·7, 11·6,

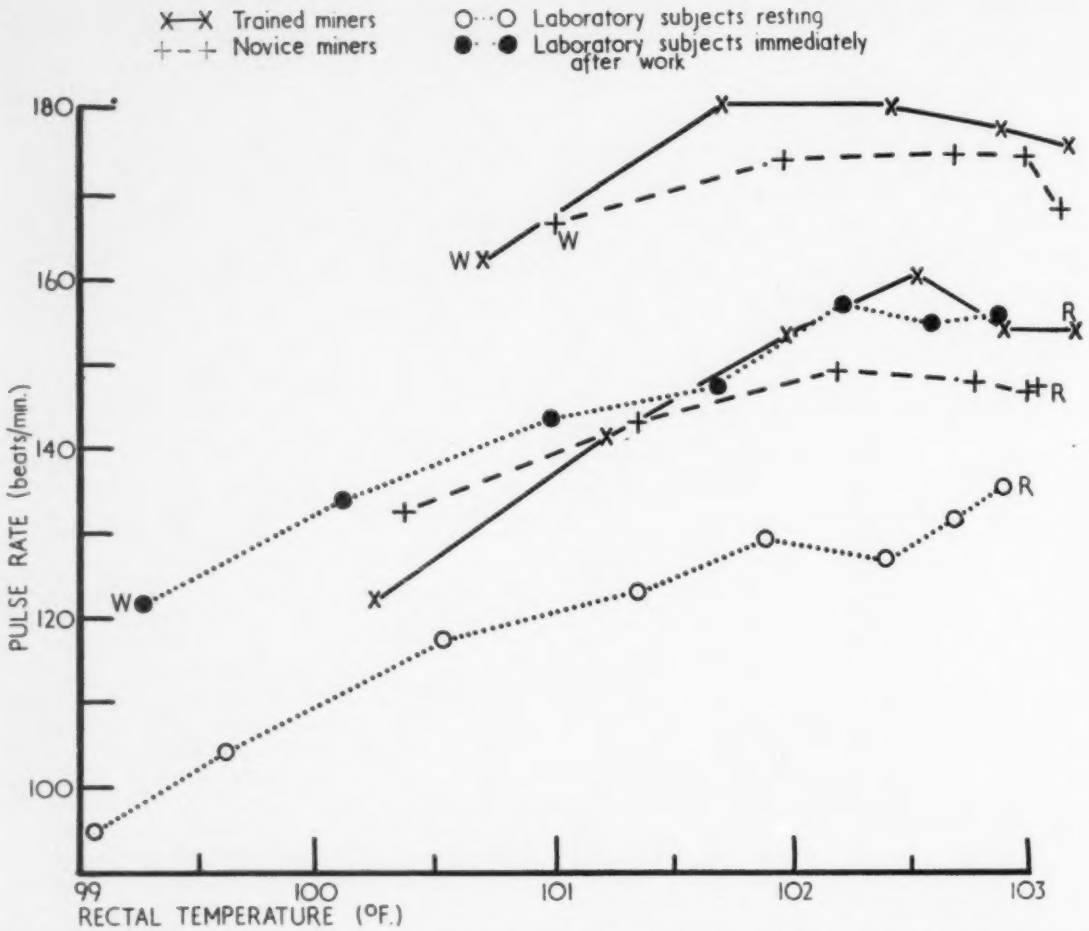

FIG. 4.—Tests at 95° F. effective temperature: the mean pulse rates and rectal temperatures for each successive period of rest and work. The values obtained after rest are marked R and those immediately post-work W. Overall metabolic cost of routine was 2 met.

and 10·7 ml./min. over the periods 12–92, 32–112, and 52–132 min. respectively. The novice miners therefore sweated at approximately the same rate as the laboratory subjects and the trained miners considerably faster.

Tests at Effective Temperature 89 to 90° F.—Four series of tests were done underground in this climate, two on one day, two on the next. Twelve trained workers, six of whom had been tested in the severe climate, and five novices, three of whom had been in the earlier tests, were observed. Four trained men and two novices, although tested in the second series of the day, were present though resting while the first series was in progress, hence when tested had already been exposed to the climate for two to three hours; the other subjects had only the usual unavoidable delay between arriving underground and the test. The laboratory subjects were tested in a climate of the same effective temperature but hotter: dry-bulb temperature 95·2° F., wet-bulb 89·5° F., air movement 50 ft./min., basic effective temperature 89·5° F.; they were also tested in 91·9° F. dry-bulb, 91·2° F. wet-bulb, "still" air, effective temperature 91° F. Unpublished work in this laboratory has shown that in this range rectal temperature rise and sweat output are determined by the effective temperature irrespective of the dry-bulb temperature (see Fig.6), hence exact reproduction of the mine test conditions was not attempted. The effect of a prolonged wait in the warmth before starting the test was also observed at 91° F. effective temperature: two sets of subjects entered the climatic chamber

together and while one set was being tested the second set rested in the heat. All tests, both underground and in the climatic chamber, were carried on for 132 min. (six cycles).

Rectal Temperature and Pulse Rate Changes.—Fig. 3 shows the rectal temperature changes for each of the three groups at effective temperatures 89 to 95° F. As in the tests at the higher temperature, and for the same reason, the initial temperatures of the laboratory subjects were lower than those of the miners. The novices began the test with a higher mean rectal temperature than the trained men and maintained this difference throughout; a similar differential between unacclimatized and acclimatized workers has been described by Wyndham, Strydom, Morrison, Du Toit, and Kraan (1954). In this case, however, probably because of the smallness of the novice group, the difference was not statistically significant. The rectal temperature rise for the first four cycles in the underground tests, comparable with the last four cycles in the climatic chamber tests, was: for the novices, 0·52 ± S.E. 0·25° F. from a mean initial temperature of 100·1° F., and for the trained workers, 0·52 ± S.E. 0·17° F. from 99·53° F. For the corresponding period in the laboratory tests the rise was less, 0·33 ± S.E. 0·14° F. from 99·6° F.; the difference is not, however, statistically significant. After resting for two and a half hours in "still" air at effective temperature 91° F. the mean rectal temperature of the laboratory subjects rose from 99·2 ± S.E. 0·19° F. to 99·65 ± S.E. 0·10° F.: the same differential was maintained between those who were tested immediately and those who had been waiting in the heat throughout the whole six cycles of the test. The final mean rectal temperatures were 100·73 ± S.E. 0·35° F. and 101·2 ± S.E. 0·35° F. in the immediate and delayed tests respectively. Analysis of variance showed that these differences were statistically significant ($P = 0·01$).

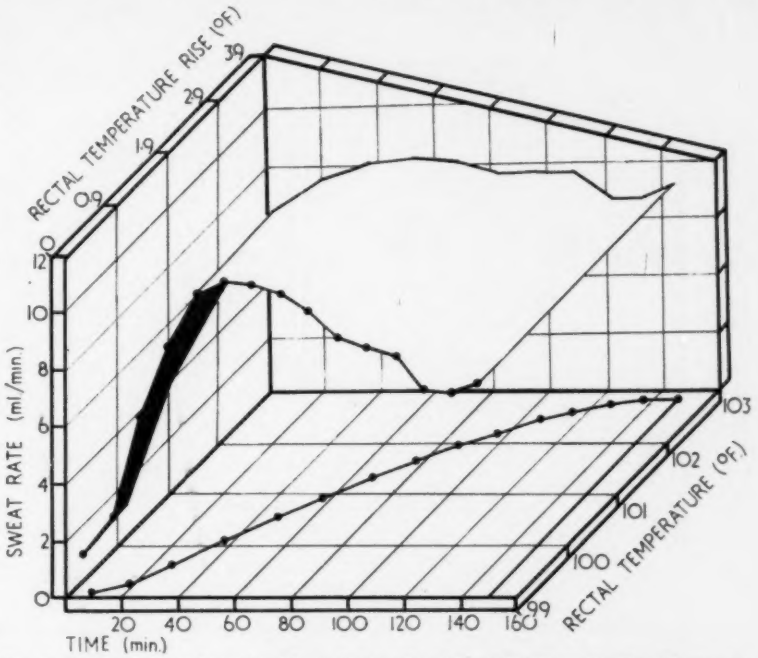

FIG. 5.—Isometric three-dimensional figure showing the relationship between duration of exposure, sweat rate, and rectal temperature for the laboratory subjects working at 2 met. at 95° F. effective temperature. The "front edge" of the riband (indicated by spots) shows the change in sweat rate with time, and the width of the riband shows the rise in rectal temperature from the mean initial temperature of 99·1° F. The "shadow" on the floor of the figure shows the change in mean rectal temperature for successive 8- and 12-min. periods, so it is not quite identical with the curve shown in Fig. 3, where recorded temperatures are plotted.

In Fig. 7 the mean pulse rates for each cycle for each group are plotted against the corresponding mean rectal temperature. The low pulse rates found were in most cases associated with lower rectal temperatures, and when this fact was taken into account pulse rates were the same in all groups; gross differences between the pulse rates of the laboratory subjects on the one hand and that of the miners on the other were not seen in this non-stressful climate. An apparent tendency for the trained miners to have higher pulse rates than the novices could not be confirmed statistically.

Sweat Rates.—The tests on the miners were complicated by an unexpected effect of the long wait before the test in the warmth of some of the subjects. Although the men were resting and never visibly sweating during this period, their subsequent sweat response to work was much diminished. Gross differences between the sweat responses of the trained and novice workers could not be detected in this climate; on the other hand, the mean sweat rate, estimated statistically as before, of 11 men tested with the minimum of delay was 8·75 ml./min. while the mean rate for the six men tested after a three-hour wait was only 3·5 ml./min.; this difference is statistically

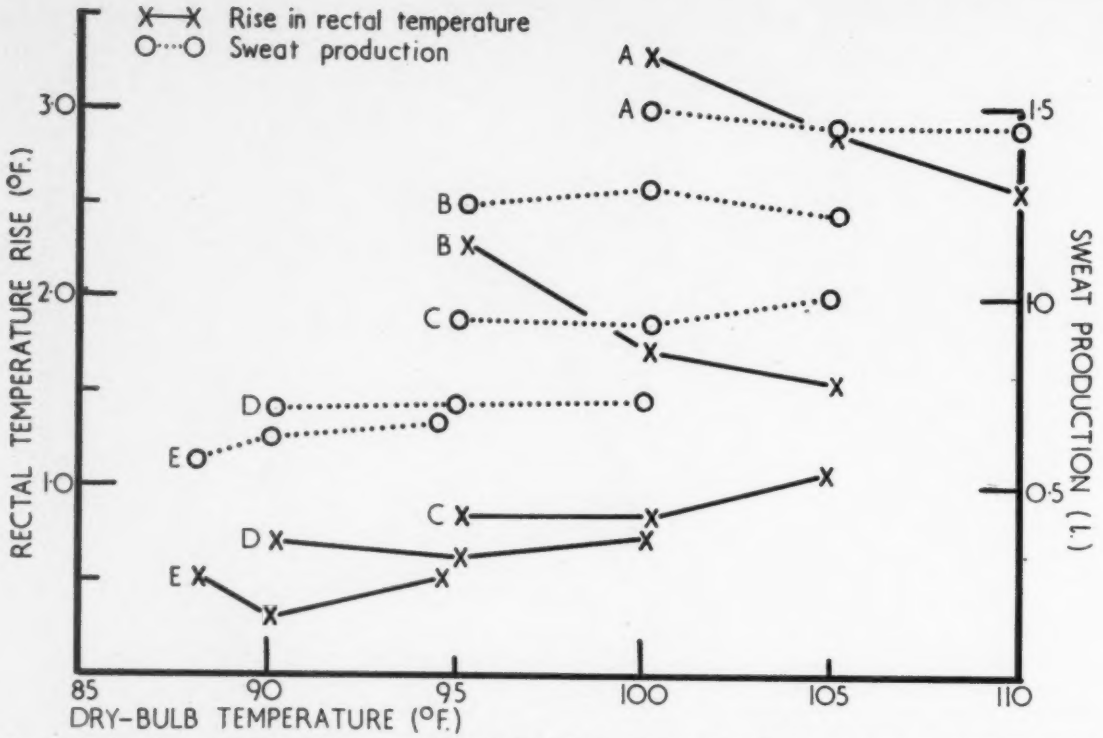

FIG. 6 (*a*).—The effect of dry-bulb variation. The letters A, B, C, D, E against the curves indicate the effective temperatures at which they were obtained, *viz.*, 95, 92·5, 90, 87·5, and 85° F. respectively.

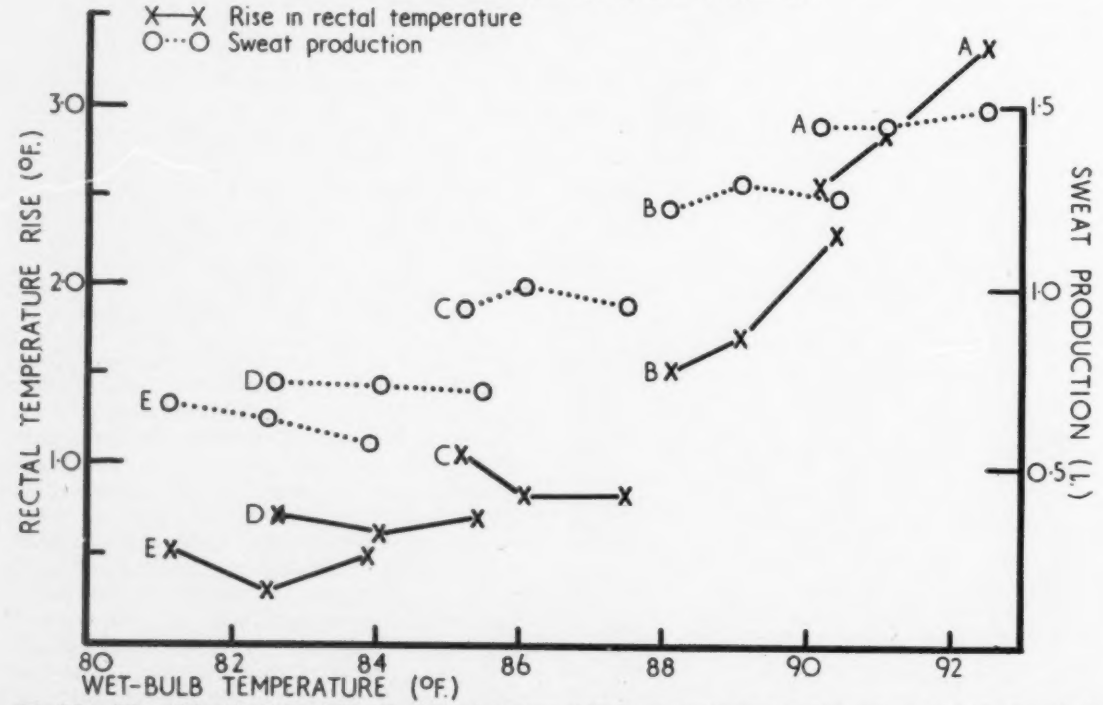

FIG. 6 (b).—Effect of changing the wet-bulb. Physiological responses of locally acclimatized men working nude at 2 met. in different basic effective temperatures. Each effective temperature was obtained in three different ways (unpublished observations by Fletcher and Ladell). In each case the two-hour period from 12 to 132 min. of the exposure is covered.

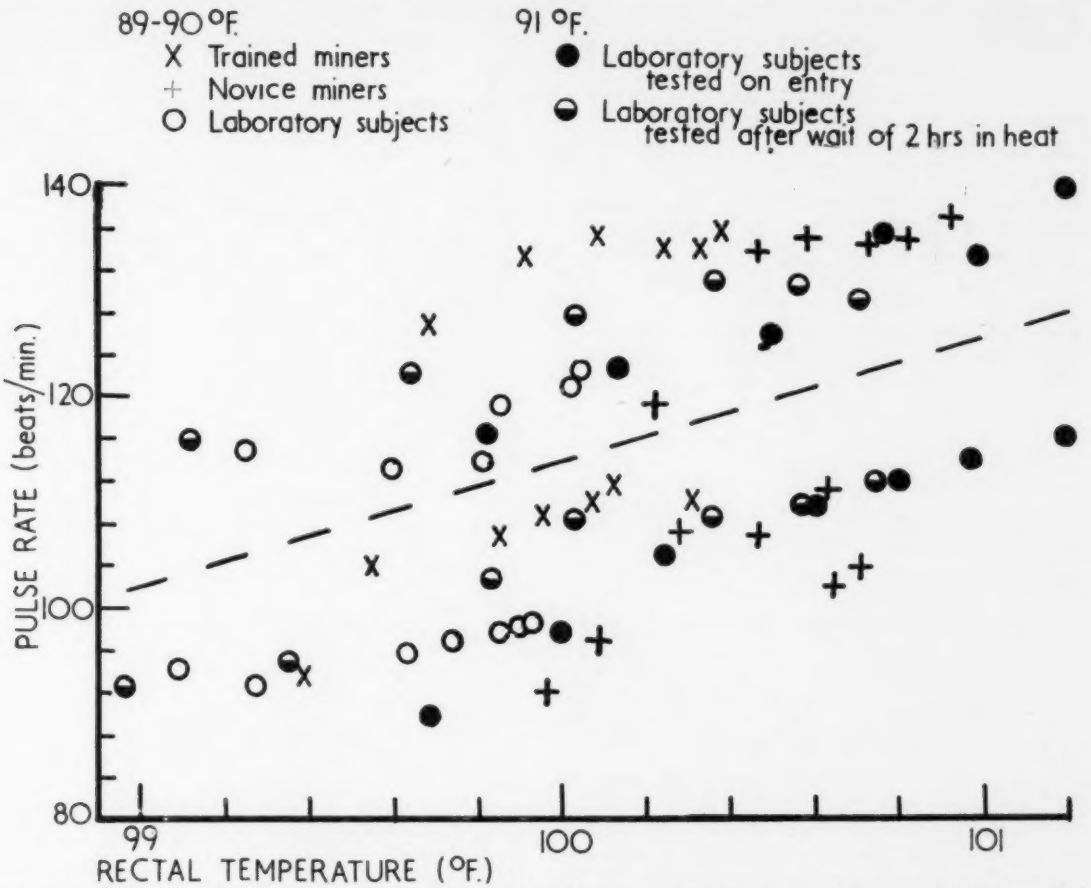

FIG. 7.—Tests at 89 to 90° F. effective temperature: scatter diagram showing the mean heart rates and rectal temperatures during a standard routine at 2 met. Each point represents the mean for the group concerned at one particular time; all points above the broken line are values obtained immediately after work, and points below the line are resting values.

significant ($P < 0.01$). The mean sweat rate (corrected for body weight) of the laboratory subjects tested at effective temperature 89·5° F. was 8 ml./min., approximately the same as that for the miners tested without delay. In the tests at effective temperature 91° F. the laboratory subjects showed the same diminution of sweat response after waiting; the mean two-hour loss, uncorrected, for the group was 830·5 ml. when tested immediately, and 589 ml. after a two and a half hour wait in the warmth; this difference is statistically significant ($t = 2.56$, $P < 0.02$).

This diminution of sweating with a wait in the heat was apparent to the eye, and was particularly noticeable in enclosed areas such as arms inside sweat-collecting bags. In the laboratory tests the mean rate of accumulation in the bags was about 0·5 ml./min. in men tested without a wait, but after a wait scarcely this amount of sweat was collected over a 20-min. period.

Chloride Concentration of Sweat.—Weiner and van Heyningen (1952) have shown that the estimation of salt losses in sweat from the concentration of chloride in samples collected in arm-bags is inaccurate; but at high sweat rates and in saturated atmospheres the error is small (Ladell, 1948a) and there is no alternative field method of estimating salt requirements. Sweat samples were collected from miners in both series of tests; the arms were washed with mine water instead of distilled water, but the error due to this was negligible as the chloride content of the water was only 2 mg./100 ml. (expressed as sodium chloride).

The rise in the chloride concentration of the arm sweat with duration of exposure usually seen in tests under artificial conditions (Weiner and van

Heyningen, 1952) was not marked in the underground tests, possibly because the men were partially or wholly acclimatized (Ladell, 1945). In the 95° F. effective temperature the mean concentrations expressed as sodium chloride were: for the untrained workers, 0·316, 0·321, and 0·385 g./100 ml. for periods 0 to 40, 40 to 80, and 80 to 112 min. respectively. The corresponding values for the trained miners were: 0·284, 0·321, and 0·332 g./100 ml. The mean values for all samples were: for the untrained workers, 0·354 ± S.E. 0·019, and for the trained men, 0·312 ± S.E. 0·022 g./100 ml. If both trained and untrained are considered as belonging to the same population and allowance made for individual variation in an analysis of variance as in Table 3,

TABLE 3
ANALYSIS OF VARIANCE OF CHLORIDE CONCENTRATION IN SWEAT OF TRAINED AND UNTRAINED WORKERS

Source of Variation	No.	Degrees Freedom	Sum of Squares	Variance	Comparison with Error	
					z value	P
Individuals	16	15	361088·2	24072·2	0·920	Less than 0·1%
Time of sample	3	2	27995·2	13997·6	0·996	Less than 1·0% More than 0·1%
Training ..	2	1	20578·4	20578·4	0·842	More than 1·0% Less than 5·0%
Discrepancy (error)	—	29	110749·2	3818·9	—	—
Total for all sources	48	47	520411·0	—	—	—

it is found that, though the direct comparison between the means for the two groups by the t test indicates no significant difference, the comparison of the variance due to training with that due to error gives a z value which lies between the 5% and the 1% points. This suggests that, in a properly controlled series of tests, lower chloride concentrations would be found in the sweat of men after they had been trained to work in the heat. The chloride concentration of the sweat from the laboratory subjects was intermediate between those for the trained and the untrained miners; the mean concentration in the samples collected in the last 40 min. of the exposure at 95° F. effective temperature was 0·361 g./100 ml.

In the cooler conditions the sweat contained less chloride. In the underground tests the mean concentrations for the three successive periods were respectively in the immediate tests: 0·219, 0·225, and 0·251 g./100 ml.; and in the delayed tests 0·230, 0·265, and 0·300 g./100 ml. In the laboratory tests at effective temperature 91° F. the mean concentrations in samples collected in the last 40 min. were 0·252 and 0·232 g./100 ml. in the immediate and delayed tests respectively.

Degree of Acclimatization of the Miners.—The ratio (mean sweat production/mean rise in rectal temperature) increases exponentially with successive exposures to heat to a maximum at full acclimatization. The equation describing this rise has been derived for a standard test in which the subjects are followed for four cycles of the same work and recovery routine as was used in the mine tests, in air moving at 50 ft./min., dry-bulb 100° F., and wet-bulb temperature 93·5° F. If the ratio under these conditions, the "S.L.T.," is determined for a group of men, their degree of acclimatization may be assessed numerically from the equation as equivalent to so many days of artificial acclimatization (Ladell, 1951).

The corrected effective temperature (C.E.T.) of the more severe of the two climates in which the underground tests were carried out was approximately the same as the C.E.T. for the standard test, but the wet-bulb temperature was higher; unpublished work in this laboratory has shown that at effective temperatures above 90° F. the rectal temperature rise is more affected than the sweat rate when the wet bulb is changed and the effective temperature is kept constant; in some cases the sweat production is hardly affected at all (Fig. 6); the S.L.T., calculated from the figures obtained in the underground tests, would therefore be too low. On the other hand, sweat production is as good a statistical index of acclimatization as S.L.T. in the standard test; the mean sweat loss in the 80-min. period from 12 to 92 min. of the set routine in the standard climate, corrected for a body weight of 65 kg., the "C.S.L.," is given by:

$$C.S.L. = 1295 - 610e^{-0.17D}$$

where D is the equivalent number of days of artificial acclimatization. In the hotter underground tests, however, although the effective temperature was correct the subjects were already sweating before the test started, and hence a further correction had to be applied to the C.S.L. value before it could be used to estimate acclimatization. The necessary correction was determined by calculating the C.S.L. for the laboratory subjects in the same climate for cycles 1 to 4, 2 to 5, and 3 to 6 inclusive: the values were 859, 935, and 857 ml. respectively. The delay in the underground tests was equivalent to at least one and possibly two cycles; the observed C.S.L. values were therefore multiplied by the factor

$$\frac{859}{\frac{1}{2}(935-857)}$$

to correct for this, and this adjusted value used in the calculation of degree of acclimatization, with the results shown in Table 4. Table 4 gives the values for the laboratory subjects for comparison : (*a*) 10 months before, when they were in approximately the same state as they were in these tests, that is, just after the wet season and with no recent exposure to heat, and (*b*) six months later after regular weekly exposure to heat, with the development of some artificial acclimatization ; this had been lost before the present series of tests as can be seen from Table 4. The trained miners were, as shown by Table 4, nearly fully acclimatized, but the untrained men and the laboratory subjects had both an equally low degree of acclimatization. Table 4 also demonstrates how an estimate of acclimatization from the S.L.T. is too low when a climate of the right effective temperature but of the wrong wet- and dry-bulb combination is used.

Discussion

Both the untrained miners and the laboratory subjects had approximately the same degree of heat tolerance which was, in fact, less than that of Europeans who lead an active life in the West African tropics (Ladell, 1951). The novices are given no acclimatization before they start underground and, although they may be assigned to districts where conditions are apparently beyond the tolerance limits, no illnesses of any sort attributable to heat have been reported from this mine. Even the fully trained men, although hyper-acclimatized, do not, when formally tested, have an unusually high heat tolerance in spite of their apparent ability to work under intolerable conditions.

Wyndham, Bouwer, Devine, and Paterson (1952) emphasize the importance of work rate in determining heat tolerance ; this is something which the West African miner has learnt for himself. The observed mid-shift falls in rectal temperature almost certainly indicate some slackening of the work rate. The few tests done showed that work in the stopes was at times equal to Wyndham's " hard work " ; at this rate even his acclimatized men reached limiting body temperatures (102° F. and higher) within four hours at 90° F. saturated ; no such limitation was observed here even when the men remained in the stopes indicating much lower sustained work rates. But contributing to the mid-shift fall was the withdrawal into roads and side-ties, where there was considerably more air movement, during blasting ; this enforced break in the middle of each shift was probably the the most important factor in the men being able to tolerate the theoretically intolerable. Before working conditions are stigmatized as " impossible", therefore, it is important to define these conditions very carefully ; not only must temperature, humidity, and air movement be considered but it is necessary to know the work rate and also the work pattern for the shift, and the duration and frequency of any enforced or tacitly permitted withdrawals to less severe conditions. The observed body temperature changes, however, indicated that the mean work rate of these men was low, about

TABLE 4

ASSESSMENT OF EQUIVALENT DEGREE OF ARTIFICIAL ACCLIMATIZATION OF GROUPS TESTED FROM CORRECTED SWEAT LOSS IN THE INDEX PERIOD AND FROM SWEAT LOSS PER UNIT RISE IN RECTAL TEMPERATURE

Group	Test Used and Index Period Taken	Corrected Sweat Loss (ml.)	Rectal Temperature Rise (°F.)	Sweat Loss (ml.)	Equivalent Artificial Acclimatization Estimate (days) from	
					S.L.T.	Corrected Sweat Loss
Laboratory subjects, time (*a*)	Standard acclimatization conditions : 12–92 min.	947	2·27	437	4·2	4·1
Laboratory subjects, time (*b*)	Standard acclimatization conditions : 12–92 min.	1,157	2·33	535	9·4	9·3
Laboratory subjects	Mine test conditions :					
	12– 92 min.	859	2·62	314	1·0*	2·0
	32–112 min.	936	2·83	330	1·3*	3·1
	52–132 min.	857	2·16	397	2·9†	1·9
Trained miners	Mine test underground :					
	12–92 min. observed	1,302	2·69	484	6·3*	—
	12–92 min. adjusted	1,246	—	—	—	14·8
Novice miners	Mine test underground :					
	12–92 min. observed	968	2·69	360	2·0*	—
	12–92 min. adjusted	928	—	—	—	3·0

*These values are too low as the rise in rectal temperature is unduly high owing to the high wet-bulb temperature.
†This value is too high as at this period of exposure the rectal temperature is no longer rising rapidly.

2 met., but if they had worked harder they might not have lasted even half a shift ; the economics of allowing a working environment to develop in which productivity is so severely cut down (probably by more than 50%) needs careful examination.

In the tests at 95° F. effective temperature the mean rectal temperature changes of both trained and untrained men were the same, in spite of their differences in sweat rate, although individually higher temperatures were reached by the novices. At this temperature and humidity evaporative cooling is severely limited (Winslow and Herrington 1949 ; Ladell, 1951) by pure physical considerations, and even the novices were secreting sweat faster than it could be evaporated ; evaporative cooling was therefore the same in both groups, apart from any slight advantage the trained men may have had from any lower chloride content of their sweat (Macpherson and Newling, 1954), and unless there were any gross differences in skin temperature, which was not measured, cooling by convection and radiation will also have been the same. Under these conditions, therefore, which were representative of the working conditions in several parts of the mine, the normal processes of physiological adaptation were of little use in helping the men to maintain thermal equilibrium, a state of affairs which is as undesirable physiologically as the limitation of work rate is economically. It follows from this that additional acclimatization is of no great value to the West African miners ; this would not apply to men working in hotter, dryer mines where there is no physical limitation to evaporation as in the Indian fields (Caplan, 1944).

The differences between these results on acclimatization and those reported by Wyndham and his team are due first to these tests having been carried out underground, with consequent delays, and not in a climatic chamber ; and, second, none of the men tested here was completely raw ; even the novices had an inherent acclimatization of three days, as has been observed in other West African indigenes (Ladell, 1950). With this degree of acclimatization most of the cardiovascular adjustments to heat have already taken place (Eichna, Bean, Ashe, and Nelson, 1945). This was indicated by the absence of any real difference in heart rate between the two groups although one novice did complain of giddiness. The trend of the heart rates to be lower in novices than in trained men, though not statistically significant, may be associated with the fact that among those tested the latter were the smaller men. In the severe climate the laboratory subjects had significantly slower heart rates, both at work and at rest, than the miners ; as this difference disappeared in the less severe climate, training itself cannot have been the cause, but, on the other hand, as the tests in the severe climate were the first done there may have been a factor of apprehension at the unfamiliar routine. In the cooler climate, although differences in heart rate were seen between the three groups, these were associated simply with differences in body temperature ; these differences did not themselves indicate any differences in response to heat stress. Relatively minor increases in body temperature are accompanied by an obvious quickening of the heart and for this reason, as these tests show, it is misleading to assess stress response on heart rate alone.

The judgment of stress by sweat rate alone also has limitations. Wyndham's charts (1954) show that the trained Rand miners would have lost approximately 3·2 l. of sweat in a four-hour routine in the severe climate and about 1·2 l. in the milder climate. The corresponding figures for the M.R.C. teams (1947) P4SR would have been 10 l. (estimated by extrapolation) and 2·9 l. respectively ; if the miners tested here had sweated at the rates observed in the short tests for a full four hours their losses would have been nearly 4 l. in the severe climate and 2·2 l. in the other climate. At the high temperatures there was thus a very great discrepancy between the P4SR and the observed rates, as was also found by Wyndham, Bouwer, Devine, and Paterson (1952) for Bantu miners, but this discrepancy was less marked in the cooler climate ; the M.R.C. team point out that discrepancies are likely to occur at high predicted rates, owing to the physiological impossibility of sweating at such rates. The discrepancy between the sweat rates observed here over a two-hour period and those found by Wyndham over a four-hour period are entirely attributable to sweat gland " fatigue ". This falling off in sweat rate after a period of exposure was at one time associated only with high rates of sweating (Robinson and Gerking, 1947), but these tests show that it occurs even when sweating is minimal. In the tests at 90° F. effective temperature, both in the laboratory and underground the sweat response to a standard work stress was much diminished after a long rest period in the same climate, even though the subjects sweated but little during their rest. The significance of this physiologically is still under investigation ; if there is a decline in actual ability to sweat after prolonged but minor stimulation then this phenomenon would be an important factor in the genesis of heat stroke ; if, on the other hand, it indicates an approach to a thermal equilibrium, so that there is less need to sweat and it is in fact

an adaptation, then a preconditioning rest in heat before work may be advisable.

From the rate of sweating observed in the formal tests the miners at their normal work probably lost at least 4 l. and in some districts twice as much sweat in an eight-hour shift. This is very much more than the observed weight losses during the shift and the men must therefore drink freely when underground avoiding "voluntary dehydration" (Adolph, 1947). Their daily sweat loss includes 10 to 20 g. of sodium chloride, using the bag samples as an indication, but in spite of the fact that no salt drink is supplied down the mine no case of heat cramp has ever been reported from this mine, although this degree of salt deficiency in Europeans would certainly result in heat cramp (Ladell, 1949); from this and also from laboratory observations it does appear that the indigenous West African is not susceptible to this condition. It is important, nevertheless, that salt should be available in sufficient quantities to make good their daily salt losses, which, as these studies show, may be considerable.

Summary

The working conditions in a deep West African gold-mine were found to be markedly beyond those usually considered, from laboratory experiments, to be tolerable. The severity was due chiefly to high humidity and low air movement; dry-bulb temperatures were not excessive.

No illnesses directly attributable to heat had been reported from this mine; observation of the men at work showed that they avoided heat stress (*a*) by taking frequent rests, and (*b*) by having a lengthy enforced withdrawal during blasting at mid-shift into cooler, well-ventilated parts.

There was no indication that the West African deep miner has an usually high heat tolerance.

The importance of investigating work rhythm as well as the climatic conditions when assessing the tolerability or otherwise of working places is emphasized.

This work was carried out at the suggestion of Dr. R. L. Cheverton, then Director of Medical Services, Gold Coast. The investigation was made by kind permission of the Ashanti Goldfields Corporation, and I am indebted to their management and staff at Obuasi for all the facilities and help afforded. I also wish to thank Dr. J. T. MacIntyre, of New Consolidated Goldfields, for his assistance and advice underground while the work was in progress.

It should be noted that since the investigations reported here were carried out a completely new ventilation system has been installed in the Obuasi mine.

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THE INFLUENCE OF INSPIRED AIR TEMPERATURE ON TOLERANCE TO WORK IN THE HEAT

BY

A. R. LIND

From the M.R.C. Climatic and Working Efficiency Unit, Department of Human Anatomy, Oxford

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In mines rescue operations two main types of self-contained breathing apparatus are used by men working in irrespirable atmospheres. One of these types of apparatus uses compressed oxygen and the other liquid air as the source of oxygen supply for the wearer. Each type of apparatus has its own distinct advantages in use, and these advantages have long been recognized. The present investigation deals only with one aspect and this does not prejudice the merits of other aspects of the apparatus.

It is recognized that the temperature of the inspired air may well prove to be a limiting factor for working men. Haldane (1915) refers to the local respiratory effect of high wet-bulb temperatures. He found that when men were exposed to hot environments at a wet-bulb temperature of 45° C. (113° F.) they were able to breathe "pretty freely" even during hard work. Killick (1932) states that when subjects at rest in cool ambient conditions breathed hot, moist air they did not experience discomfort until the wet-bulb temperature of the inspired air reached 54·5 to 63° C. (130 to 145° F.), and found breathing tolerable until the wet-bulb temperature reached 59 to 65° C. (138 to 150° F.). When her subjects were working on an ergometer "at a rate equivalent to walking at 4 to 4½ m.p.h." these limits dropped to 51·5 to 54·5° C. (125 to 130° F.) and 54·5 to 60° C. (130 to 140° F.) wet-bulb temperatures, respectively.

Haldane also remarks that atmospheres which are very hot, but dry, can be breathed without great discomfort. This is confirmed by Killick, who found that, for subjects at rest, dry air of temperatures of up to 186° C. (367° F.) could be breathed in comfort, and the corresponding temperature for men working was 104·5° C. (220° F.).

During a recent series of experiments, inspired air temperatures in the two types of breathing apparatus commonly worn in mines rescue work were recorded in hot environments under conditions simulating rescue operations, and their importance physiologically is emphasized in the results.

Description of the Circuits in Two Types of Apparatus

Apparatus 1.—This apparatus uses a cylinder of compressed oxygen as the source of supply of oxygen for the wearer. The oxygen is led from the cylinder to one compartment of a breathing bag. The gas then passes through a cooling device, and thence through a one-way valve to the mouthpiece. The exhaled gas passes through a non-return valve to the other compartment of the breathing bag. The two compartments are in communication at the bottom of the bag, in which is placed a charge of soda-lime. The gas must pass through the soda-lime, which removes the CO_2, and the "regenerated" gas then mixes in the inhalation side of the breathing bag with the incoming oxygen from the cylinder. Soda-lime produces heat and moisture when it absorbs CO_2, and the cooler is introduced to the circuit in an attempt to reduce the temperature of the absorbed air. The coolant used is sodium phosphate, which liquefies at about 35° C. (95° F.), so that in theory the temperature of the air in the circuit should not greatly exceed 35° C. until all the coolant is liquefied.

Apparatus 2.—This apparatus uses liquid air as the source of supply of oxygen for the wearer. From the mouthpiece the exhaled gas is led through a non-return valve to a caustic-soda canister, where the CO_2 is removed. The "regenerated" gas is then led to a breathing bag which consists of only one compartment, and acts solely as a reservoir. The gas is led from the breathing bag to the mouthpiece by way of a non-return valve. The liquid air evaporates in its container, and is introduced to the circuit at a point along the tube between the caustic-soda canister and the breathing bag. No cooler is incorporated, since the low temperature of evaporation of liquid air is sufficient to compensate for the heat evolved in the caustic-soda canister.

Methods

Thirty-six volunteer mine workers took part in the series of experiments. The men were divided into three

teams of 12, each of which comprised six men wearing Apparatus 1 and six wearing Apparatus 2; each team was exposed three times to saturated still-air environments while performing a set task, and one team was exposed a fourth time, doing a different task. These tasks are described below. Six separate climates were investigated, involving 54 individual experiments on men wearing Apparatus 1, and 54 individual experiments on men wearing Apparatus 2, where one task was performed. A further six individual experiments with each type of apparatus involved a different task.

The saturated temperatures in ° C. used were :—

Exposure	Saturated Temperature C°*		
	Team 1	Team 2	Team 3
1	29·4 (85)	30·8 (87·5)	29·4 (85)
2	29·4 (85)	30·8 (87·5)	33·6 (92·5)
3	32·2 (90)	35 (95)	37·8 (100)
4	37·8 (100)†		

* ° F. in parentheses. † Different task (B).

The air-speed in the room was less than 20 ft./min., although the effective air-speed was about 175 ft./min., due to the subject's movements. Room temperatures were thermostatically controlled in both dry- and wet-bulb temperatures to $\pm 0{\cdot}5°$ C.

Task A.—The task set in all but one exposure was of 65 minutes' duration, as follows :—

65 min. { 30 min. (Energy cost, 171 Cal./m.²/hr.) { 5 × 4 min. walking at 2 m.p.h. carrying a 50-lb. sandbag, spaced by 5 × 1 min. rest, followed by 1 × 5 min. walking at 2 m.p.h. carrying a 50-lb. sandbag. } ; 5 min. (Energy cost, 89 Cal./m.²/hr.) { Rest. } ; 30 min. (Energy cost, 248 Cal./m.²/hr.) { 6 × 4 min. building a sandbag stopping, using 24 sandbags of 50 lb. each, carrying each bag singly for 15 ft. to build the stopping, spaced by 6 × 1 min. rest. } }

Task B.—This task was performed only once, in a highly saturated temperature, and was not expected to continue for 65 minutes. It comprised "sandbag stopping" cycles of five minutes each as shown in the second half of Task A and was continued until the men were approaching their limit of tolerance.

Inspired air temperatures were taken once during each one-minute rest, and twice during the five-minute rest, until the end of the 65 minutes or until the men were considered unable to continue, or until they stopped voluntarily. The inspired air temperature was taken by a 30 s.w.g. copper-constantan thermocouple situated in the flexible tubing leading to the mouthpiece. The site for the thermocouple was chosen about 9 in. from the mouthpiece because the valve is not in the mouthpiece, and some temperature fluctuation occurs near the mouthpiece itself on the inspiration side due to pressure and convection currents on expiration.

The air within the apparatus was assumed to be saturated. It was not possible within the experimental routine to make measurements on both wet- and dry-bulb thermocouples. On only one occasion, in a pilot exposure, were dry and wet thermocouple readings taken, and the results indicate full or nearly full saturation.

Results

Figs. 1a and b show the mean inspired air temperature curves for each type of apparatus at each environmental condition for all tests in which the men performed Task A. The mean initial and final rectal temperatures for men wearing either type of apparatus were not significantly different. The horizontal line 38·8° C. (101·8° F.) shows the mean rectal temperature at the conclusion of these experiments. It can be seen that while the curves show some scatter, the pattern in each case with each apparatus is very similar.

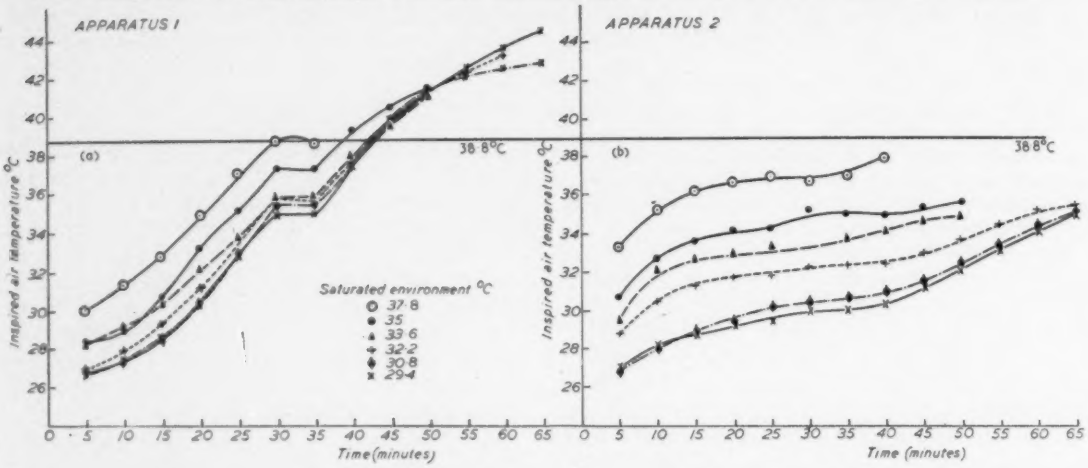
Fig. 2 shows the mean inspired air temperature curves of all the tests in which all the men took part while doing Task A in either apparatus. In the experiments at higher temperatures, the men were unable to complete 65 minutes, so that the number of readings represented by each mean falls from the rest period towards the end of the experiment, although the number of readings in each mean never falls below 22. The curves of inspired air temperatures for individual experiments follow the same pattern as the mean curves shown in Figs. 1 and 2.

Fig. 3 shows the mean of the first recorded inspired air temperatures at each of the six environments investigated. These readings were taken five minutes after entering the hot room, during the first minute rest after walking for four minutes at 2 m.p.h. Since the men had performed the same task in those five minutes on each occasion, presumably the mean measurements shown reflect the rise in temperature due to environmental temperature. The difference shown in initial inspired air temperatures between the two types of apparatus is probably due to the different CO_2 absorbents used, and to differences in the heat capacities in the two types of apparatus.

Whereas the environmental temperature influences the initial temperature of the air within the apparatus, the two types of equipment follow distinct and characteristic curves (Fig. 2) so that the inspired air in Apparatus 1 increases more rapidly and is about 5° C. (9° F.) higher after 40 minutes than in Apparatus 2, and this difference increases to about 8° C. (14°5· F.).

Considering again the averages of all the experiments with Task A, in all six environments (Fig. 2) we see that the inspired air temperature in Apparatus 1 starts lower than that in Apparatus 2, but rises more quickly, passes that of Apparatus 2 in 20

FIG. 1 (a and b)—Inspired air temperature in two types of breathing apparatus during work in various saturated environments.



minutes (Fig. 2), passes rectal temperature in about 40 minutes, and reaches a mean peak of 43·7° C. (110° F.) after 65 minutes. In Apparatus 2 the temperature rises more slowly but steadily until finally 36·3° C. (97·3° F.) is reached after 65 minutes. From these curves Apparatus 2 is obviously the more efficient apparatus in maintaining low inspired air temperatures, despite the fact that by using caustic soda as a CO_2 absorbent it has a greater amount of heat generated within the circuit.

In all the experiments with subjects performing Task A, men wearing Apparatus 1 finished with inspired air temperatures lower than 40° C. eight times in 54 individual experiments, and only twice with temperatures lower than 38·8° C. (the final rectal temperature). All these cases occurred at the two highest temperatures, 35° and 37·8° C., saturated environments, when the short period of survival in those environments did not allow the inspired air temperature to rise to this level, despite the higher initial starting temperature. In men wearing Apparatus 2, the inspired air temperatures surpassed 40° C. only three times in 54 individual experiments, twice by the same man. On only five occasions in 54 experiments did they surpass 38·8° C.; these occurred in saturated environments at 29·4, 30·8, and 37·8° C.

Fig. 4 shows the mean inspired air temperatures for the 12 men who performed Task B in a saturated environment at 37·8° C. (100° F.).

FIG. 2.—Inspired air temperature recorded in both types of apparatus while subjects performed Task A (mean values).

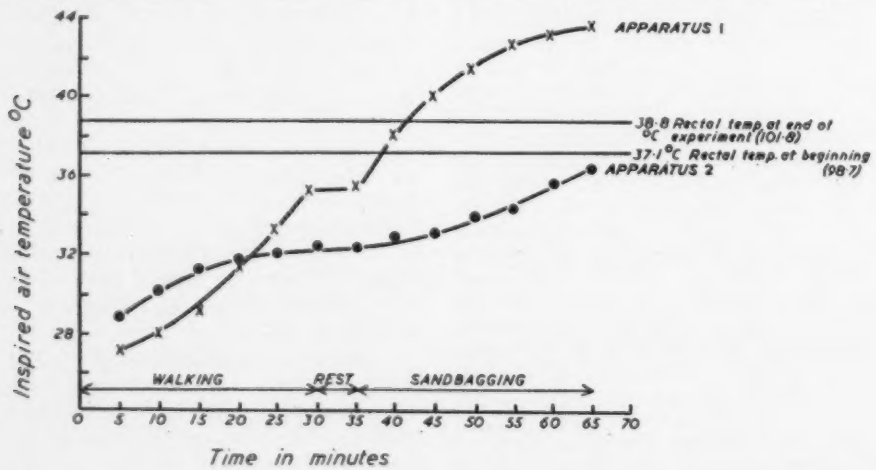
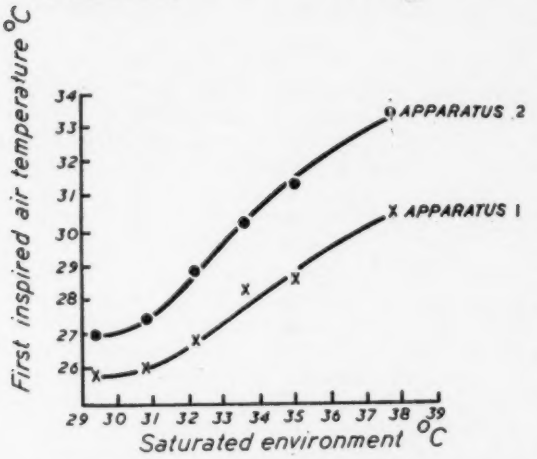


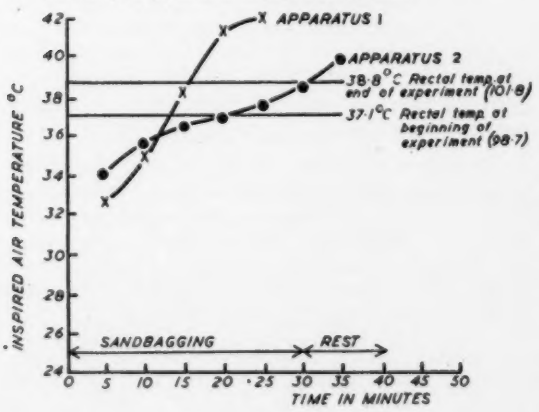
FIG. 3.—Increase in first recorded inspired air temperature (after five minutes in chamber) due to increase in environmental temperature (mean values).



When the men were performing Task B the temperature of inspired air in both types of apparatus rose more rapidly than when they performed Task A, and although the men could not continue working for longer than half an hour, with both types of apparatus the inspired air temperature rose above body temperature. The temperatures shown for Apparatus 2 reached a higher value than expected, largely because the last two points represent a mean of only three and two subjects respectively, one of whom had an unusually high inspired air temperature.

The subjects were asked before the start of each experiment to indicate by a sign if and when they considered that the inspired air had become uncomfortably hot. After the experiments each man was questioned on this point, whether or not he had already volunteered such information. The men were found to be firm in their views and questioning revealed not one who wished to change his mind. Only one complaint was volunteered by a wearer of Apparatus 2, when, after 55 minutes of work, the inspired air temperature reached 42° C., subsequently reaching 43° C. at the end of the experiment. In Apparatus 1, in 33 of the 54 individual experiments the subjects volunteered the information that the air had become uncomfortably hot. During any individual experiment, the temperature of the inspired air regarded as that at which the subject complained was that taken during the minute rest subsequent to the receipt of the information. These temperatures ranged from 39 to 43° C. (102·2 to 109·4° F.). The final temperatures achieved by those subjects who did not feel that the inspired air was uncomfortably hot ranged from 38 to 42·25° C. (99·95 to 108·05° F.). Whether or not complaints were made, most of the subjects considered that they could have continued for a longer period if the temperature of the inspired air had not been so high.

FIG. 4.—Inspired air temperature recorded in both types of apparatus while subjects performed Task B (mean values).



The " tolerance time " of the men in all these experiments shows that the wearers of Apparatus 1 were able to continue work for an average of 50 minutes, and the wearers of Apparatus 2 continued for one of 54·5 minutes, or 9% longer.

Discussion

Although it is recognized that each type of apparatus has its special merits in use, the physiological significances of the inspired air temperature in these conditions are clear. When the inspired air temperature reaches body temperature, this channel of heat loss is denied to the thermoregulatory system, and when it rises above body temperature the body is gaining heat through the lungs. When men are wearing either type of breathing apparatus a large part of the trunk is shielded and evaporative cooling from this area is considerably reduced, so that in environments where dissipation of heat by evaporation is already restricted, the normally unimportant role of cooling by evaporation of exhaled air assumes greater significance. If it is possible to achieve an environmental temperature at which all heat exchanges between body and environment are prevented, then the rate of production of heat within the body itself, *i.e.*, the rate of expenditure of energy, will determine the tolerance time. If the breathing apparatus is worn when the inspired air temperature is below body temperature the expected tolerance time will be lengthened, and when the inspired air temperature is above body temperature, then the expected tolerance time will be shortened.

It is evident from the results obtained in the present series of experiments that, disregarding for the moment other merits of the apparatus, when the inspired air temperature alone is considered, Apparatus 1 had a detrimental effect on the wearer after about 40 minutes, i.e., for 25 minutes of the 65-minute task, while Apparatus 2 did not impose this physiological burden. An examination of the rates of rise of temperatures (see Figs. 2 and 4) in the breathing circuit indicates, as expected, that the demand for oxygen and the rate of production of CO_2 and therefore of CO_2 absorption by soda-lime or caustic soda and resulting production of heat closely controls the inspired air temperature. This is more evident in the curves for Apparatus 1 than for Apparatus 2, and probably reflects the relative efficiency of the methods of cooling the air in the circuit. During the five minutes' rest period in the experiment, the temperature either remains steady or falls. During Task B, in which the men start with the heavier work routine, the rate of rise of temperature is noticeably greater, but the rate of rise of temperature in Apparatus 1 at the lighter work routine is disproportionate to an extent which makes it seem probable that if the lighter work had been continued there would have been a greater difference in the tolerance times of the subjects wearing the different types of apparatus.

Much of the blame for the inspired air temperature in Apparatus 1 rising so dramatically is due to the inefficient design of the cooler. Inspection of the cooler after the experiments showed that the coolant was never more than 60% liquefied, seldom more than 40% liquefied, and in a number of instances no liquefaction was evident. It seems likely that with an efficient cooler the inspired air temperature may well be reduced, although there is also some indication that even in full efficiency, a chemical cooling method of this type may not provide the best answer; this will obviously be true of higher environmental temperatures, where the environment itself will affect the coolant.

The inspired air temperature at which discomfort was experienced in the present experiments is much lower than the figures quoted by Haldane or Killick. Haldane found that when men were exposed to and breathed a saturated temperature of 54·5° C. (130° F.) ordinary breathing was more or less painful, that at a saturated temperature of 48·9° C. (120° F.) work was hardly possible, but that at 45° C. (113° F.) saturated temperature, "the air was not too hot to breathe pretty freely" even when quite hard work was done. Haldane and his subjects were completely exposed to these climates in a hot chamber. Killick, whose subjects were in a cool environment and breathed hot, moist air through a tube, found that for men at rest the lowest temperature which caused discomfort was 54·5° C. (130° F.), and, for men doing quite hard work, this limit dropped to 51·5° C. (125° F.). In the present investigation, where the subjects were exposed to saturated environments at various temperatures while wearing self-contained breathing apparatus, respiratory discomfort was felt first at 39° C., 6° C. lower than the figure quoted by Haldane, and 12° C. below that quoted by Killick. It is likely that the explanation for this lies in three factors: (1) the levels of comfort are reduced with an increase in the rate of work, and the "sand-bagging" routine of the present experiments is very heavy work; (2) the men during the present series were wearing apparatus, and that some of the discomfort noticed may have been due to soda-lime dust reaching the throat; (3) the individual variation in the subjects used in the present series is greater than that of the subjects used by Killick or Haldane.

In deciding which type of apparatus is to be used, the effects of high inspired air temperature must be balanced against the practical advantages and disadvantages not specified here, paramount in which is the safety of the wearer.

Summary

Inspired air temperatures in two types of self-breathing apparatus are given for men working at two different tasks in various saturated environments.

From these results it is shown that in the present design, so far as inspired air temperatures are concerned, wearers of Apparatus 1 are at a physiological disadvantage compared to the wearers of Apparatus 2. It must be emphasized that this refers only to the effects of inspired air temperatures, and other comparisons are necessary for true evaluation of the relative worth of the two types of apparatus in operational conditions.

There is some evidence to suggest that the figures previously obtained for saturated temperatures which men can breathe in comfort when they are working may not apply to wearers of closed-circuit breathing apparatus.

I wish to thank Dr. J. S. Weiner and Mr. R. F. Hellon, of the Medical Research Council's Climatic and Working Efficiency Unit in Oxford, for help and advice, and the National Coal Board, who provided administrative and experimental services, and finally the 36 subjects without whose whole-hearted cooperation these experiments would not have been possible.

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INVESTIGATIONS INTO THE EFFECTS OF EXPOSURE TO TRICHLORETHYLENE IN MECHANICAL ENGINEERING*†

BY

E. GRANDJEAN, R. MÜNCHINGER, V. TURRIAN, P. A. HAAS, H.-K. KNOEPFEL, and H. ROSENMUND

From the Institute of Hygiene and of Industrial Physiology of the Swiss Federal Institute of Technology, Zurich, the Institute of Aviation Medicine, Dübendorf, and the Laboratory of Medical Chemistry of the Cantonal Hospital of Zurich

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Trichlorethylene (tri) is a solvent widely used in mechanical engineering, where it is employed mainly for cleansing and degreasing. Its main advantages are that it is non-inflammable ; is an excellent degreasing agent, and is relatively inexpensive.

Although tri was for a long time considered to be only very mildly toxic, there has been, in recent years, a great increase in research and investigation into its toxic effects. Severe poisoning is characterized by a narcotic action which, if exposure is sufficiently prolonged, may lead to death. Chronic inhalation, continued over a period of years, seems mainly to attack the nervous system, the symptoms most frequently met with being giddiness, headaches, insomnia, tiredness, troubles of the vegetative nervous system, neuritis, and inability to tolerate alcohol.

The maximum allowable concentration (m.a.c.) has been fixed by various institutions and authors as follows :—

American Governmental Conference on Industrial Hygiene	200 p.p.m.
I.C.I. (England)	400 p.p.m.
U.S.S.R.‡	9 p.p.m.
Parmegiani (University of Milan)	100 p.p.m.
Elkins (Boston)	150 p.p.m.

Ever since Barrett, Cunningham, and Johnston (1939) found that some of the tri is eliminated in the urine in the form of trichloracetic acid, several writers have set out to analyse the urine of workers and to take the quantity of trichloracetic (T.C.A.) acid found as the criterion of exposure. Ahlmark and Forssman (1951a) examined 122 workers dealing with tri and found subjective disturbances in 50% of these men who were eliminating between 40 and 75 mg. of trichloracetic acid per litre of urine. In almost all cases where elimination exceeded 100 mg. per litre disturbances were present. These writers concluded that an elimination of up to 20 mg. of trichloracetic acid per litre of urine could be tolerated.

In view of the fact that until now there has been no systematic investigation into exposure to tri in the mechanical engineering industry, we considered that such a study would be useful. We decided to proceed by determining the concentration of tri in the air in workshops and by measuring the elimination of trichloracetic acid by workers, at the same time inquiring into their general state of health.

Method

Analysis of the Air.—We collected tri vapours in ethylic alcohol 95% by passing the air to be successively analysed through two washing bottles (impingers). The volume of air passing through the washing bottles was checked and determined by means of a flowmeter.

The tri absorbed was then quantitatively measured according to the method of Truhaut (1951), which we modified slightly. This method is based on a coloured reaction between the tri and the pyridin in an alkaline medium (Fujiwara's reaction). Our modifications of Truhaut's method were as follows :

To 1 ml. of the alcohol solution of tri we added 3 ml. of pyridin (purified) and 1 ml. of 1% NaOH in alcohol. After shaking, the solution was heated for five minutes in a water-bath at 65° C. A violet-red colour developed uniformly throughout the solution. When it cooled, 2 ml. of distilled water was added, and after two minutes the intensity of the colour was measured with a Beckman's spectrophotometer and the extinction determined

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†This paper was submitted in French and has been translated.

‡According to a circular letter by Ahlmark (Sweden) and an article published by Bardodéj, Berka, Chalupa, Nesvadba, and Vyskočil (1952).

at a wavelength of 550 μ (or 5500 Å.). We prepared a graph for every series of analyses.

Analysis of Trichloracetic Acid in the Urine.—Ahlmark and Forssman (1951a) found that there was only a very slight variation in the elimination of T.C.A. in the course of the day. During our preliminary experiments, we ourselves noted that the quantities of T.C.A. varied only slightly from day to day for the same worker. We therefore confined ourselves to examining samples of urine taken at any hour of the day.

The quantitative analysis of the T.C.A. was carried out according to Fabre's (1949) method which we modified slightly. After treating with tungstate according to Fabre's directions, to 1 ml. of filtrate we added 3 ml. of pyridin and 1 ml. of N.NaOH (purified). The next steps were identical with those described above for the quantitative analysis of tri in the air. It should be noted that we had to prepare a separate graph for every specimen of urine in respect of its colorimetric analysis.

Clinical Examination.—Every worker underwent a detailed clinical examination, which included occupational and personal histories, physical examination of the respiratory and circulatory organs, liver, etc., neurological examination of pupillary reflexes, of cutaneous and deep sensitivity, of cutaneous and proprioceptive reflexes, of hearing and of sight, psychiatric examination, especially in respect of fixation memory, attention, comprehension, ideation, and affectivity.

For this purpose we carried out a clinico-psychiatric examination together with the tests of Meggendorf, Bourdon, Rorschach, and Jung, Knoepfel's (1952) "thirteen mistakes" test, and Bleuler's (1943) "ass laden with salt" test. These tests, in conjunction with the psychiatric examination, are likely to reveal a group of symptoms which, following Bleuler (1954), we call the psycho-organic syndrome. This syndrome is mainly characterized by a diminution of memory, a reduction of the power of reflexion and understanding, and by changes in affective powers. It is found in a more or less acute form in patients suffering from a chronic, diffuse lesion of the brain and more especially after serious trauma to the brain, in cerebral arteriosclerosis, and in many cases of poisoning by lead or mercury, or by organic solvents.

A blood examination, including a count of red corpuscles, a determination of the haemoglobin, and the sedimentation rate, and a differential white cell count, was made.

We also carried out biochemical tests to determine non-protein nitrogen, plasma protein, serum bilirubin, blood cholesterol, serum iron and alkaline phosphatase, the Takata-Ara reaction, the Hangar reaction, the Weltmann test, the cadmium reaction, the Quick test, and the blood calcium.

An analysis of urine, including an examination for albumin, sugar, and urobilinogen, was made.

We examined in all 80 workers, seven of whom stopped working with tri from three weeks to six years before. Twenty-three of the workers were not clinically examined and in these we confined ourselves to a case history of subjective troubles and an analysis of trichloracetic acid in the urine. These 80 workers were employed in 24 workshops belonging to 10 different factories of the Swiss mechanical engineering industry.

In all these factories tri is used in degreasing equipment. This usually consists of tanks in which quantities of solvent, varying from a few litres to a few hundred litres,

TABLE 1

AVERAGE CONCENTRATION OF TRI IN THE AIR OF THE WORKSHOPS

Workshop	Near the Tank			Centre of the Workshop		
	No. of Analyses	Extreme Range	Averages	No. of Analyses	Extreme Range	Averages
Open Tanks						
I	8	6–84	30·5	8	15–63	37·6
II	4	17–23	21·8	2	8–10	9
III	5	27–60	35·6	4	13–18	15
IV	5	1–8	5	1	2	2
VI	1	325	325	3	127–335	225
VII	5	85–198	131·4	1	133	133
XI	2	57–68	62·5	—	—	—
XII	4	29–51	40·3	—	—	—
XV	2	45	45	—	—	—
XVI	2	30–35	32·5	—	—	—
XVIII	7	27–46	33·5	2	25–27	26
XXII	3	18–27	22·3	1	27	27
XXIII	1	25	25	1	10	10
XXIV	1	20	20	—	—	—
Averages	—	—	59·5	—	—	53·8
Closed Tanks						
V	2	13–56	34·5	—	—	—
VIII	1	11	11	—	—	—
IX	1	13	13	—	—	—
X	1	35	35	1	35	35
XIII	2	23–40	31·5	—	—	—
XIV	3	18–20	19	—	—	—
Averages	—	—	24	—	—	—

(p.p.m. = parts per million = ml. of vapour/cu.m. of air)

are heated to 70 or 80° C. Generally speaking, there are two kinds of tanks in these factories : (1) open tanks, in which the worker dips the parts to be cleaned in the solvent, and (2) closed tanks, where the dipping is done automatically without any interference by the worker during the degreasing process. All the open tanks were equipped with refrigerator coils to condense the tri vapours, together with an air exhaust system at the side of the tank. A similar installation was included in the closed tanks in order to get rid of the tri vapours.

Results

Concentration of Tri in the Air in Workshops.— Specimens of air for chemical analysis were taken at a height of 160 cm., that is to say, above the edge of open tanks or in the immediate proximity of the loading apertures of closed tanks, or again at a few metres' distance from the tanks, generally speaking, in the centre of the workshops near where the loading and unloading of dipping containers took place. The taking of air samples lasted from five to 10 minutes and workers were requested to work as usual during this time. Thus the number of dippings varied from one sampling to the next.

In the 20 workshops we made in all 84 analyses of air, 60 close to the tanks and 24 in the centre of the workshop (Table 1).

In most cases concentrations of tri near the tanks varied from 20 to 40 p.p.m. If we compare the amounts obtained near open tanks with those obtained near closed tanks we notice a difference in favour of the latter. The amounts obtained in the centre of the workshops were very similar to the amounts obtained close to the tanks.

In workshops VI and VII we noticed that the men worked without taking precautions, allowing parts to drip outside the tanks and occasionally using tri outside the tank.

In two workshops we took two sets of readings at different times of the day in order to test the effect of a variation in the conditions in which the experiments were made. The amounts shown in these two sets of readings are set out in Table 2.

In workshop I concentration varied during the morning between 6 and 53 p.p.m., while in workshop XVIII it varied between 25 and 40 p.p.m. According to our observers on the spot, these variations in concentration should be attributed mainly to local conditions of ventilation at the time of the analysis ; other factors, such as the length of time parts were allowed to dry within the tank and the shape of the parts dipped, also played an important part.

Twice we came across open tanks where degreasing was going on at the vapour stage. The readings we took close to these tanks showed amounts similar to those found at open tanks, namely an average concentration of 37 p.p.m. on five readings, with extreme limits of 8 and 63 p.p.m.

TABLE 2

VARIATIONS IN THE CONCENTRATION OF TRI IN THE AIR

Time	Place of Analysis	Kind of Work	p.p.m.
9.30	Workshop I, centre of workshop	Drying a basket	15
9.40	„ „ near the open tank	Dipping and drying a basket	6
10.00	„ „ centre of workshop	Unloading a basket	15
10.10	„ „ near the open tank	Dipping a single part	10
10.25	„ „ „	„ „	8
10.35	„ „ „	Withdrawal of part and drying	30
10.59	„ „ centre of workshop	Dipping and drying a basket	29
11.10	„ „ near the open tank	„ „	53
11.20	„ „ centre of workshop	Drying a basket and of large parts	39
11.30	„ „ near the open tank	Dipping and drying a basket	31
11.45	„ „ centre of workshop	Drying a basket and washing an apron	32
9.15	„ XVIII, near the open tank	Filling the tank with tri	40
9.25	„ „ „	Drying a basket and hand cleaning of various parts	27
10.10	„ „ „	Dipping and drying 3 baskets	29
10.25	„ „ „	Dipping and drying 4 baskets	34
10.40	„ „ centre of workshop	—	25
10.50	„ „ near the open tank	Dipping and drying 5 baskets	29

On two occasions we noticed workmen using cold tri in vats wholly lacking in safety devices or any ventilation system. Concentration of tri in the air during this work varied from 67 to 157 p.p.m., the average amount being 105 p.p.m.

We also determined the concentration of tri in the air of the workshops in relation to the length of

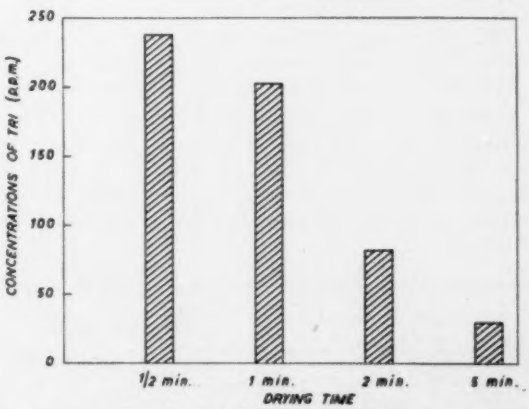


FIG. 1.—Concentration of trichlorethylene in the air in relation to drying time of parts inside apparatus.

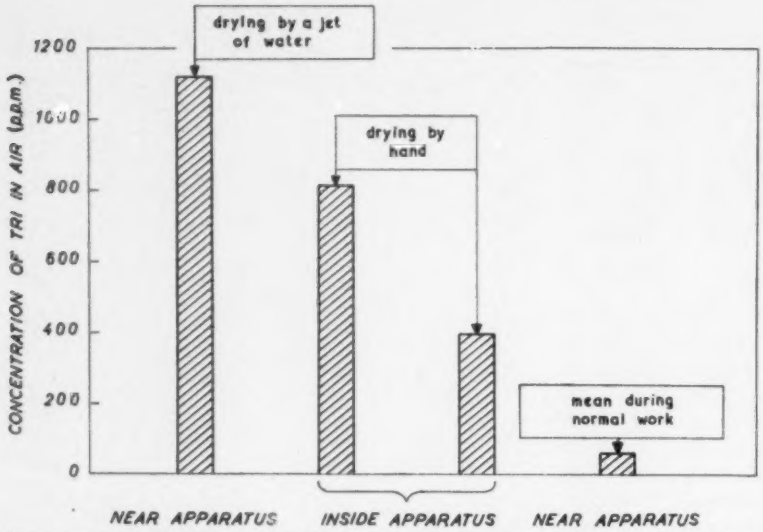


FIG. 2.—Concentration of trichlorethylene in the air during the cleaning of the apparatus.

time parts were left to drip and dry inside the tank. The results of this experiment are shown in Fig. 1. We found that the concentration of tri in the air was considerably reduced when drying time inside the apparatus was prolonged from half a minute to five minutes.

Tri equipment is cleaned once or twice a week. We examined the concentration of tri near the tank during one cleaning operation. In the case in question, the workman emptied the tank, rinsed it with water from a powerful hose pipe, then got inside the tank and spent half an hour cleaning with a scrubbing brush. Analyses of the air showed a concentration of 1,120 p.p.m. outside the tank while the hose pipe was in action, with 815 and 395 p.p.m. inside the apparatus during and after the scrubbing respectively (Fig. 2).

We also made air analyses using various methods of ventilation while work was being carried on normally. The workshop under consideration was fitted with a mixed system of mechanical ventilation including both air suction and air blowing. On the upper edge of the tri tank was fixed a lateral suction pump which was intended to get rid of the rising tri vapour. The results were as follows :

Kind of Ventilation	Average Concentration of Tri in Air (p.p.m.)
No ventilation	167
Lateral suction pump at the level of tri tank	112
General ventilation and local suction pump	53

(The relatively high amounts, 112 and 167 p.p.m., found in this set of experiments were partly due to the presence of large-scale suction pumps in paint-spraying sheds close by.)

Elimination of T.C.A. by Workmen Using Tri.—In a preliminary experiment we studied the elimination of trichloracetic acid in the urine for four consecutive days by 11 workmen regularly using tri. The total amount of urine passed in 24 hours was collected and submitted to chemical analysis. Both the individual amounts and the average amounts for each workman are seen in Table 3.

TABLE 3
ELIMINATION OF T.C.A. IN URINE FOR FOUR DAYS BY 11 WORKMEN

Workman	1st Day	2nd Day	3rd Day	4th Day	Average Concentration of T.C.A. (mg./1.) for 4 Days	Average of the Total Quantity of T.C.A. (mg./24 h.) for 4 Days
a	39·6	39·1	67·4	55·1	50·3	66·1
b	246	250	309	291	274	298
c	194	269	211	153	206·8	199·5
d	128	328	320	322	274·5	186·3
e	140	74·2	121	141	119	91·3
f	22	44·1	27·3	27·4	30·2	32·6
g	212	382	259	207	265	222·8
h	65·8	91	242	408	201	240·5
i	257	268	342	332	300	313
j	101	41·5	120	155	104	145
k	51	83·6	87	74	82	75

We found in this first series of experiments that concentrations of T.C.A. in the urine varied on an average between 30 and 300 mg./1. The variations in concentration from day to day were less marked in the same man than were the differences between man and man. We also found that the total quantities of T.C.A. eliminated per 24 hours corresponded very closely to the amounts expressed in mg./1.

The results of these preliminary tests enabled us to confine ourselves, in this general study, to an analysis of one or two specimens of urine per workman.

The amounts obtained in respect of the 73 workmen using tri in the 10 factories inspected varied between 8 and 444 mg./1., the general average being 86·7 mg./1.

We tried to establish the relation between the amount of T.C.A. eliminated and the concentration

of tri in the air. By means of analyses of air, we were able to determine the concentrations of tri to which 55 of these workmen were frequently exposed. It was not possible to determine with sufficient accuracy the degree of concentration to which the other workmen were exposed. The results, which are set out in Fig. 3, show that in respect of our 55 workmen there could hardly be said to be any definite relation between the two sets of readings.

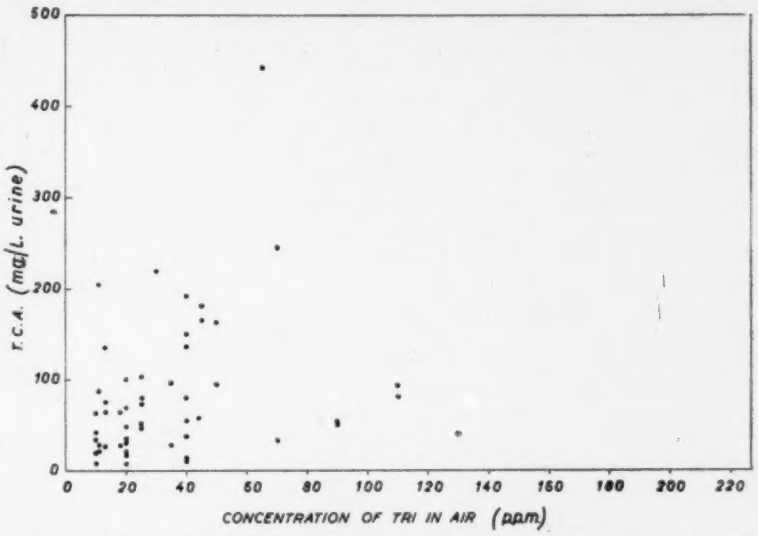


FIG. 3.—Elimination of trichloracetic acid and concentration of trichlorethylene in the air of workshops.

We noted that men working all day with tri showed on an average larger amounts of T.C.A. than those who worked only part of the time at the tri tanks. This led us to calculate in the case of 52 workmen the product of tri (p.p.m.) in the atmosphere × the length of time spent working with tri. (We lacked sufficiently accurate bases on which to make this calculation in the other cases.) In our calculations, the length of time spent working with tri was expressed as a percentage of the total of working hours. In the case of a workman spending one-third of his time in contact with tri and exposed to a concentration of 60 p.p.m., for example, we would obtain a product of 0·33 × 60 = 20. Fig. 4 shows the elimination of T.C.A. in relation to the product of the p.p.m. concentration and the length of exposure to tri ; this product we shall henceforth call the theoretical exposure. This graph shows that there is a certain relation between the elimination of T.C.A. and the theoretical exposure. Calculations have given a coefficient of correlation r = + 0·68 and a coefficient of determination B = 0·46. This means that 46% of the variations in T.C.A. may be attributed to corresponding variations in the theoretical exposure. The coefficient of regression amounted to b = 2·99. We may thus conclude that, on an average, the relation of T.C.A. to theoretical exposure is 3 : 1.

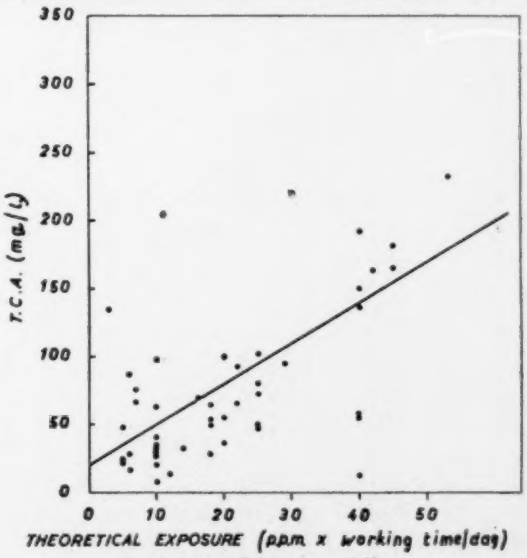
Twenty-five of our workmen spent the entire day at the tri tanks. When we compared their actual exposure with their elimination of T.C.A., we obtained the following average amounts :

Number of Workmen Spending 8 Hours/Day at Tri Tanks	Average Elimination (mg./l.)	Average Exposure (p.p.m.)
25	86·2	24·9

Ratio T.C.A. (mg./l.) : tri (p.p.m.) = 3·4 : 1.

The amounts for workmen dealing all day with tri confirmed the relation calculated above for the theoretical exposure.

The coefficient of determination, B = 0·46, together with a study of the total amounts shown in Fig. 4 showed to what extent the wide scatter of the results might affect the relation we tried to establish between elimination of T.C.A. and exposure to tri.



Correlation coefficient : r = 0·68.
Regression line : b = 2·99.
Determination coefficient : B = 0·46.

FIG. 4.—Elimination of trichloracetic acid in relation to theoretical exposure to trichlorethylene.

The ratio of T.C.A. to theoretical exposure varied in fact between the extremes 20 : 1 and 1 : 2 ; the majority of cases, however, varied between 4 : 1 and 2 : 1. The main factors in this wide disparity were (1) individual variability regarding the breaking down of tri into T.C.A. ; (2) lack of precision in considering the measurement of the concentration of tri in the air as a criterion of the exposure of the workman, seeing that the air analysed consisted merely of samples taken during working hours.

During our investigation we twice found cases of workmen whose exposure to tri did not exceed 20 to 30 p.p.m., but whose elimination of T.C.A. exceeded 200 mg./l. A thorough examination of working conditions revealed that these two men regularly cleaned the tri equipment, a job that exposed them periodically to very high concentrations of tri in the air. Another instructive example was the case of the man who spent only three to four hours per week cleaning the tri apparatus but whose elimination of T.C.A. amounted to 130 mg./l.

We tried to find if there was any relation between the elimination of T.C.A. and (1) the age of the workmen, (2) the duration of employment working with tri, or (3) the kind of apparatus used. With this in view we calculated the relation of T.C.A. to theoretical exposure for different age groups. The results appear in Fig. 5. We concluded that elimination of T.C.A. was distinctly greater in young men than in older men. There did not, however, seem to be much relation between the elimination of T.C.A. and the number of years spent working with tri.

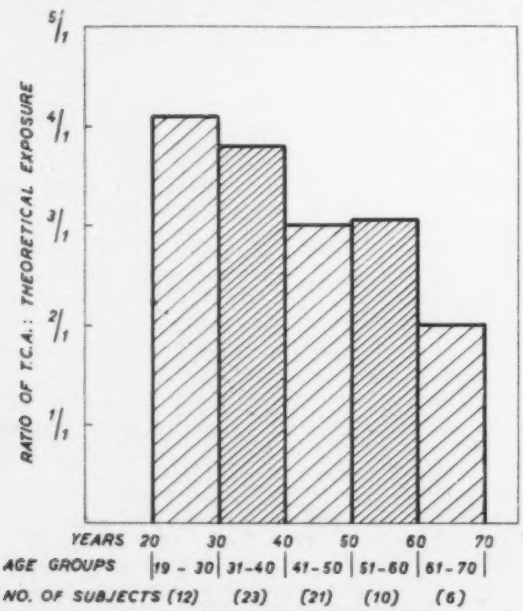


FIG. 5.—Elimination of trichloracetic acid in relation to theoretical exposure of men of different ages.

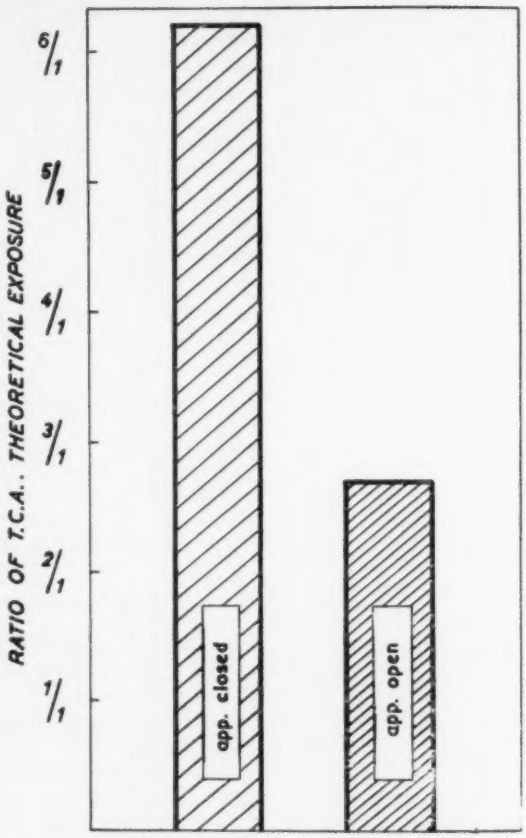


FIG. 6.—Elimination of trichloracetic acid in relation to theoretical exposures by workers dealing with closed and open apparatus.

Fig. 6 shows the average ratios of T.C.A. to theoretical exposure for both closed and open apparatus. We noted that elimination of T.C.A. in relation to theoretical exposure was very much higher for men working at closed apparatus than for men working at open apparatus. This difference is certainly due to the fact that the concentrations of tri found in the air in the region of the closed tanks are relatively low. Nevertheless, these men are occasionally exposed to very high concentrations of tri which evade air analyses, especially during the cleaning of the apparatus—a job that causes relatively high elimination of T.C.A.

We had the opportunity of studying variations in the elimination of T.C.A. by three men working

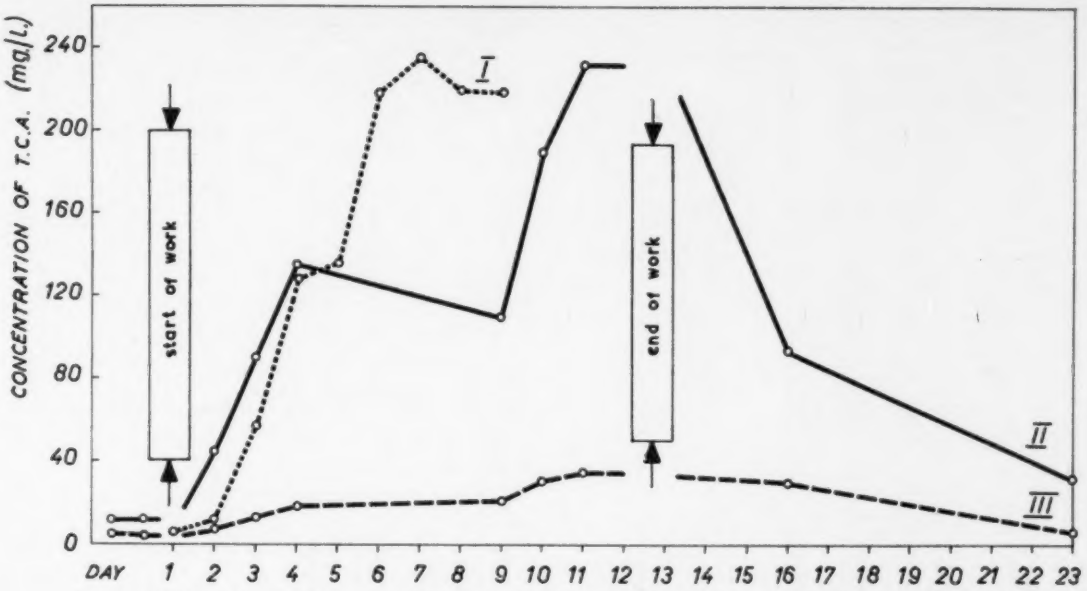


FIG. 7.—Variation in elimination of trichloracetic acid by men dealing with trichlorethylene for a fixed period.

near an open tank for a fixed period (Fig. 7). Concentration of tri in the air near the tank varied, in the case of workman No. I, from 6 to 84 p.p.m. (average 30·5 p.p.m.) and, for Nos. II and III, from 27 to 60 p.p.m. (average 35·6). For the first five to 10 days of exposure the elimination of T.C.A. in the urine increased. Three days and 10 days after exposure we still found considerable concentration of T.C.A. These results agree with observations made by Ahlmark and Forssman (1951b), by Nash and Sherwood (1953), and by Soucek, Theisinger, and Paveltrova (1952).

Medical Examination of Men Working with Tri

Case Histories.—The 50 persons (49 men and one woman) working with tri had an average age of 43 years at the time of the clinical examination. Differences of age are shown in Fig. 8.

The length of time these people were in contact with tri varied from one month to 15 years, the average being three and three-quarter years. The division into total periods of exposure is shown in Fig. 9.

In Fig. 10 we grouped together all subjective troubles. The workers themselves attributed most of their ailments to contact with tri. Complaints were sometimes made spontaneously, sometimes after questioning by the doctor. Of the 50 workers questioned, only two had no complaints; 66% complained of symptoms which, in our view, seemed characteristic of exposure to tri; 38% had had to consult their doctor about these symptoms. It is probable that, as regards most of these symptoms, any other group taken from the same social level would have shown an incidence similar

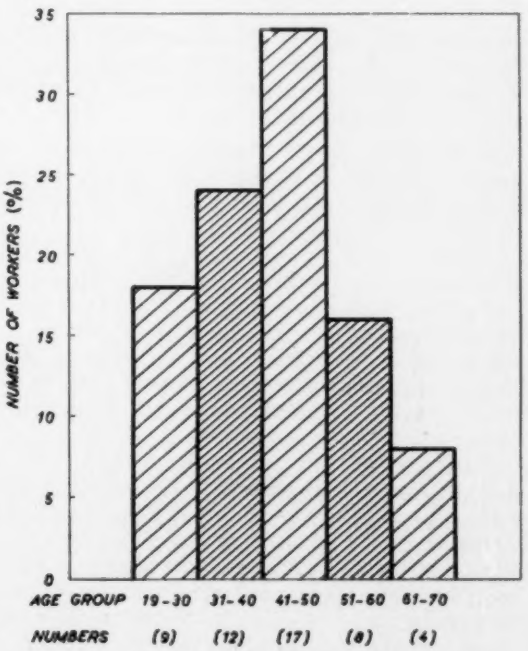


FIG. 8.—Age of workers examined

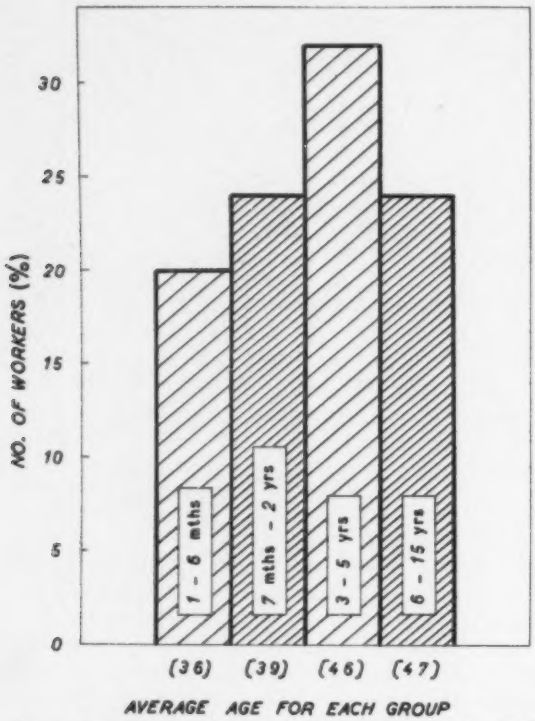


FIG. 9.—Duration of exposure to trichlorethylene of workers examined.

to that of Fig. 10. We hold, nevertheless, that the incidence of certain symptoms such as fatigue, dizziness, inability to tolerate alcohol, was particularly high in this group.

Examination of the Nervous System.—In this statistical study we distinguished between neurological changes, disorders of the vegetative nervous system, and psychical changes.

Among neurological changes we included any modification of vision, of the proprioceptive or cutaneous reflexes, of the corneal reflex, of cutaneous sensitivity, together with signs of slow tremors, of ataxia, or of nystagmus. If only those subjects showing several modifications or very pronounced symptoms are included we found neurological changes in 28% of our workers.

Disorders of the vegetative nervous system included excessive perspiration, circulatory symptoms, fine tremors, trembling eyelids, functional disorders of the gastro-intestinal system, palpitations, tachycardia, extrasystoles, praecordial pain, together with pronounced modifications of the dermographism. Confining ourselves to cases showing either several of the above symptoms in a mild form, or one serious symptom, we found disorders of the vegetative nervous system in 36% of our workers.

Diagnosis of psychical changes was based on the results of tests described above together with a clinical examination of the subjects. These examinations gave the following results :

Psychical Changes	No. of Workers (Total 50)
Diminution of fixation memory	19
Understanding slow and lacking in precision	9
General slowing down of intellectual processes	20
Paucity of associations, with lack of precision and abundance of useless detail	17
Perseveration of ideas	13
Emotional instability	13
Confabulation	9
Diminution of initiative and interests	6

We noted that 17 workers (34%) had a slight or moderate psycho-organic syndrome. In eight the psycho-organic syndrome was similar to that of persons suffering from alcoholic poisoning, arteriosclerosis, or of persons over 60 years of age. In nine cases, however, in the absence of any other possible aetiological factor, we diagnosed a psycho-organic syndrome caused by chronic exposure to tri.

Blood Tests.—Examination of the composition of the blood gave the following results :

Results of Blood Tests	No. of Workers (Total 50)
Less than 4·5 million erythrocytes per c.mm.	13
Less than 80% haemoglobin (100%=15·6 g.%)	5
Colour index less than 0·8	3
Leucocytes : more than 8,000 per c.mm.	7
Rod neutrophils : more than 10%	2
Neutrophils with segmented nucleus increase or decrease	2
Eosinophils : 5% and over	17
Monocytes : 9% and over	13
Basophils : 3% and over	2
Lymphocytes : less than 20%	4
,, : more than 45%	—
Sedimentation rate higher than 6 mm. in the first hour	5

Biochemical Tests.—These tests gave the following results :

Results of Biochemical Tests	No. of Workers (Total 50)
Proteins : more than 7·9 g.%	1
,, : less than 6·5 g.%	3
Bilirubin : more than 1·3 mg.%	0
Total cholesterol : more than 200 mg.%	5
Ester of cholesterol : less than 60%	1
Serum iron (only one analysis per person) : more than 150 γ %	11
Alkaline phosphatase : more than 4 units	6
Positive Takata-Ara reaction	0
Positive Hangar reaction (cephalin-cholesterol)	4
Weltmann test : less than 0·25‰ $CaCl_2$	13
,, ,, : less than 0·20‰ $CaCl_2$	2
,, ,, : more than 0·35‰ $CaCl_2$	1
Positive reaction to cadmium	2
Prothrombin (Quick) : less than 90%	3
Calcium : more than 10·5 mg.%	8
Residual nitrogen : more than 35 mg.%	1

We must point out that most of the figures attained deviated only slightly from normal. We were unable to diagnose a single case of liver or kidney trouble with certainty. In 10% of the workers, however, modifications shown by the biochemical tests were sufficient to warrant a suspicion that the liver was slightly diseased or at least that its function was slightly impaired. We cannot, on the basis of these chemical tests, conclude that there is any causal relation between liver troubles and contact with tri.

Various Clinical Observations.—In the 50 workers we noted various other changes which may be classified as follows :

Observations	No. of Workers (Total 50)
Pharyngitis	22
Bronchitis, tracheitis, and emphysematous conditions	9
Chronic tonsillitis	9
Conjunctivitis	3
Stomatitis	2
Periodontosis	18
Dental prosthesis	21
Bad dentition	11
Body weight less than height—100	20
Eczema	0
Dermatomycosis	2
Heart troubles	5
Systolic arterial pressure greater than 150 mm. Hg	8
Arteriosclerosis	7
Enlarged liver	13
Excessive indulgence in alcohol	7

General Remarks on State of Health.—Most of the workers who handle tri are in a low-paid category, their professional and social ambitions are almost non-existent, and their standard of living is certainly well below that of the average Swiss workman. We were not therefore surprised to find that the general health of the men examined was frequently bad.

As we were not acquainted with the normal incidence of disease in the various categories of Swiss workmen, we could not state with certainty to what extent subjective troubles and those revealed by clinical examinations might be attributed to contact with tri. It did seem to us, however, that troubles and lesions of the peripheral, central, and vegetative nervous systems were very frequent in this group. For this reason we endeavoured to establish a relation between the rate of incidence of both nervous troubles and subjective troubles and the known factors regarding exposure.

In Fig. 11 we classified workers according to their exposure to tri. We found that the rate of incidence of vegetative and neurological disorders was distinctly higher in Group III than in the other two groups. Results were submitted to statistical analysis using the Fisher (1946) 2×2 tables

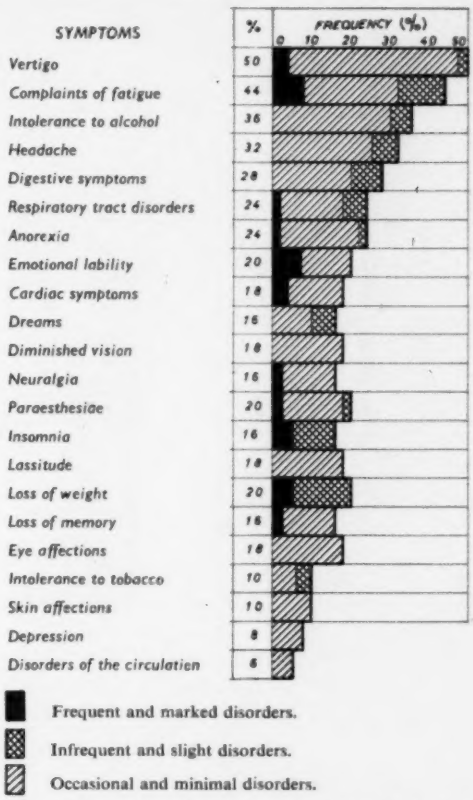


FIG. 10.—Subjective troubles of 50 workers dealing with trichlorethylene. The horizontal columns represent the rate of incidence of troubles as a percentage of the number of workers examined.

test. There were significant differences ($p = 0{\cdot}05$) in the incidence of neurological disorder between Groups I and III, while between Groups II and III there were significant differences ($p = 0{\cdot}05$) in vegetative and neurological disorders. Other differences were not significant.

Similarly, we classified our 50 workers in three categories according to the amount of T.C.A. eliminated in the urine. The results plotted in Fig. 12 show that subjective, vegetative, and neurological disorders were more frequent in Groups II and III than in Group I. Statistical analysis revealed the following significant differences ($p < 0{\cdot}01$) : subjective disorders between I and II ; vegetative disorders between I and II and between I and III ; neurological disorders between I and (II + III).

In Fig. 13 we divided workers into four categories according to the total length of time spent working with tri. Subjective symptoms were fairly equally divided between the four categories. We noticed, however, that vegetative, neurological, and psychical

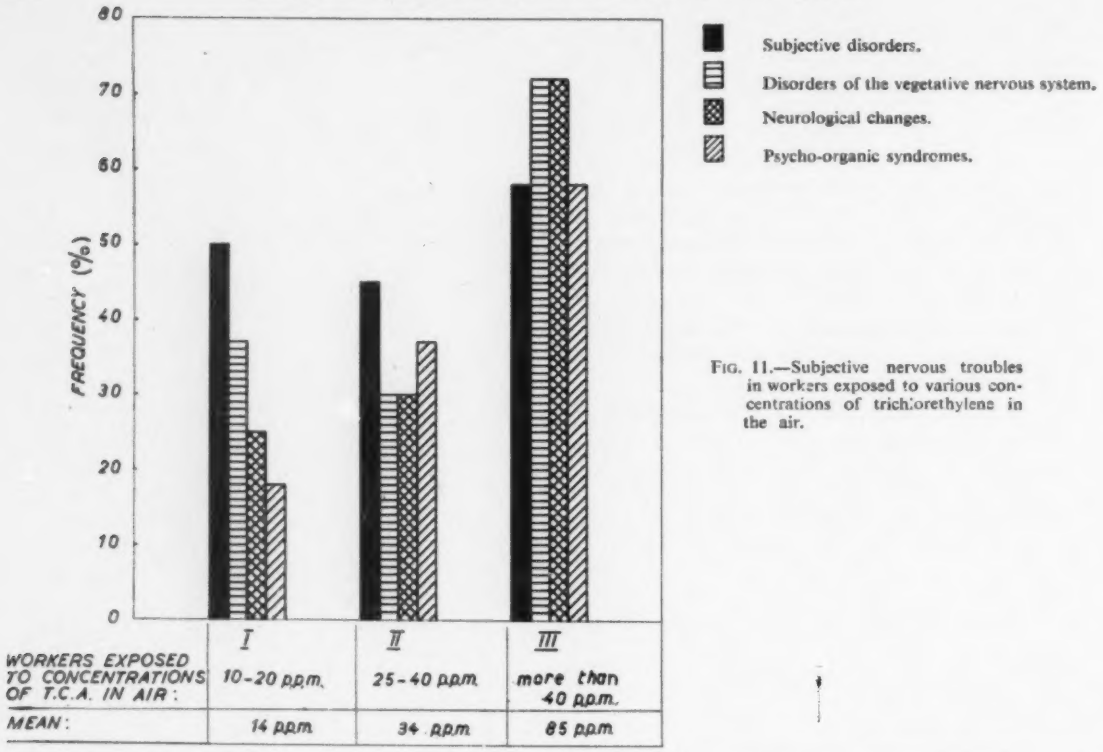


FIG. 11.—Subjective nervous troubles in workers exposed to various concentrations of trichlorethylene in the air.

symptoms increased with the length of exposure to tri. The following definite differences were shown by statistical analysis ($p < 0{\cdot}03$): vegetative disorders between I and IV; neurological disorders between I and II and between I and IV; psychical disorders between I and III and between I and IV. It would appear that the average age of each group was not the main factor in this increase. It should be particularly noted that we found neither neurological changes nor psychotic syndromes in workers who had been dealing with tri for only a few months.

All the comparisons represented in Figs. 11, 12, and 13 show that there is certainly a relation between exposure to tri and the rate of incidence of the various nervous disorders observed.

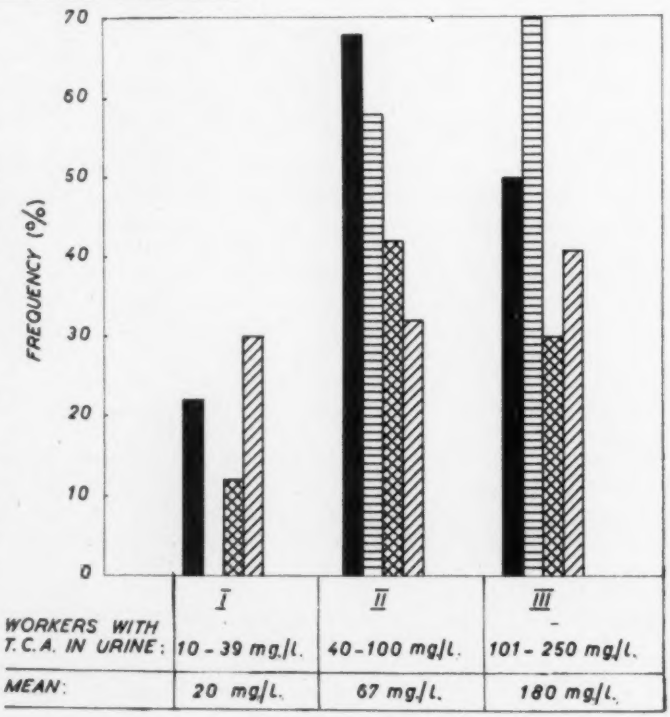


FIG. 12.—Subjective nervous troubles in workers eliminating various amounts of trichloracetic acid in the urine.

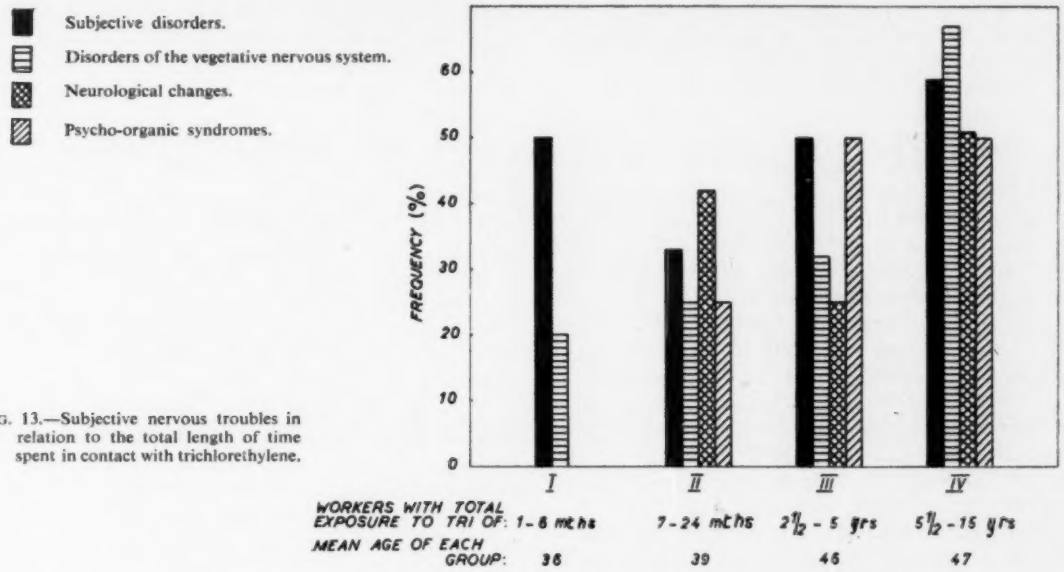


FIG. 13.—Subjective nervous troubles in relation to the total length of time spent in contact with trichlorethylene.

Discussion of Results

Our work showed that the determination of the concentration of tri in the air provided useful information regarding the efficacy of the tri plant in use and the dangers attendant on the methods of work. We had, however, to admit that often such readings provided insufficient indication of the total extent of exposure of the worker, who might sometimes inhale large quantities of tri which would not be included in the routine air analyses (special tank cleaning jobs, renewal of tri, etc.).

The simultaneous measurement of tri in the air and the amount of T.C.A. eliminated revealed the existence between these phenomena of a ratio corresponding, on an average, to the following: T.C.A. (mg./l.) : tri (p.p.m.) = 3 : 1.

This ratio differed widely from one individual to the next, but in most cases it varied between 2 : 1 and 6 : 1. These ratios were valid in respect of continuous exposure for eight hours per day and for concentrations of tri in the air varying between 10 and 100 p.p.m.

Frant and Westendorp (1950) studied the relationship between elimination of T.C.A. (in mg./l.) and exposure to tri (in p.p.m.) in the case of seven workers and found proportions varying from 4 : 1 to 1 : 1. Friberg, Kylin, and Nyström (1953) found in the case of three workers exposed for five days to tri vapours of between 100 and 150 p.p.m. an elimination of T.C.A. varying between 250 and 500 mg./l. These results were equivalent to a ratio of 2·5 : 1, 3 : 1, and 6 : 1. These few examples taken from existing data correspond quite closely to our own findings.

Barrett and his collaborators (1939) considered that the T.C.A. eliminated in the urine consisted of 5 to 8% of the tri absorbed by the human organism. Soucek and his collaborators (1952) found in nine cases exposed for five hours to concentrations of tri of between 0·5 and 1·3 mg./l. of air an elimination of T.C.A. varying between 7 and 27% of the tri absorbed, the average being 16%.

Ahlmark and Forssman (1951b) administered doses of tri of between 0·5 and 2·26 g. in 10-min. inhalation periods, and found that from 6 to 16% of the tri absorbed was eliminated in the form of T.C.A. Forssman and Holmquist (1953) observed in rats that about 4% of tri inhaled was eliminated in the form of T.C.A.

On the basis of our own results, we found that the quantity of T.C.A. in mg./l. eliminated amounted on an average to 13% of the tri inhaled by our workers during the eight-hour day

In making these calculations we worked on the basis of an eight-hour day, an elimination of urine of 1·5 l. per 24 hours, a respiratory rate of 15 l./min., a 70% absorption of tri, and a ratio of the molecular weight of tri to T.C.A. of 3 : 4.

Measurement of T.C.A. eliminated in the urine undoubtedly constitutes a valuable supplementary examination because it can reveal accidental absorption of tri which may escape air analysis. The wide discrepancies in individual elimination of T.C.A., however, prevent this method of investigation

from being a reliable guide. We consider that the determination of T.C.A. is, by itself, insufficient and should be accompanied by air analysis in order to arrive at the degree of exposure of the workers.

According to Ahlmark and Forssman (1951a), the limit of tolerance of T.C.A. should be fixed at 20 mg./l. We may conclude from our experiments that this limit of 20 mg./l. should correspond to an exposure of 5 to 10 p.p.m. On the other hand, we find that the majority of authors and of organizations dealing with industrial hygiene put forward a maximum allowable concentration of 100 to 400 p.p.m., corresponding to an elimination of T.C.A. of at least 200 mg./l. There is, therefore, a considerable discrepancy between permissible limits for both tri in the air and T.C.A. in the urine. Russian and Czechoslovak authors are alone in laying down a limit of 9 p.p.m., which corresponds to the maximum concentration of T.C.A. put forward by Ahlmark and Forssman.

Our clinical examinations revealed that most of the workers suffered from various nervous troubles which increased with exposure to tri, from which we may conclude that some, at any rate, of the troubles observed should be attributed to contact with tri. Symptoms of chronic poisoning were caused by exposure to concentrations of tri in the air varying, in general, between 20 and 80 p.p.m. the average being about 40 p.p.m. The same workers eliminated quantities of T.C.A. varying in general between 10 and 250 mg./l., the average being 96 mg./l.

From these results we conclude that the maximum permissible concentration of tri in the air for continuous work should be fixed at less than 40 p.p.m., and the corresponding limit of T.C.A. in the urine at less than 96 mg./l.

Summary

The concentrations of trichlorethylene (tri) vapours have been measured in the air of 24 workshops, and the eliminations of trichloracetic acid (T.C.A.) have been determined in the urine of 73 workers. A method based on the Fujiwara reaction was used.

The 96 air analyses gave values between 1 and 335 p.p.m., most of them lying between 20 and 40 p.p.m. The open trichlorethylene apparatus gave higher values (59 p.p.m.) than the closed ones (23 p.p.m.). A series of consecutive measurements during a period of three to four hours showed a great variation of the values due to the actual degree of ventilation and of utilization of the apparatus.

The concentration of trichloracetic acid varied between 8 and 444 mg./l. urine ; the mean value was 84·7 mg./l.

The ratio between the elimination of trichloracetic acid in mg./l. and the trichlorethylene exposition in p.p.m. for the men occupied the whole day with trichlorethylene was, in the mean, equal to 3 : 1. This ratio varies greatly, the younger workers having on an average a ratio of 6 : 1 and the elderly subjects one of 2 : 1.

The eliminated trichloracetic acid is in the mean 13% of the trichlorethylene inhaled during a work period of eight hours.

The clinical examinations showed a relatively high frequency of subjective complaints, of alterations of the vegetative nervous system, and of neurological and psychiatric symptoms. There is a relationship between the frequency of those nervous alterations and the degree of exposure to trichlorethylene.

The determinations of the concentration of trichlorethylene in the air and the corresponding elimination of trichloracetic acid in the urine show that there is a great discrepancy between the actually accepted mean allowable concentration value for trichlorethylene and that for trichloracetic acid. We conclude from our results that the mean allowable concentration for trichlorethylene should be fixed below 40 p.p.m., and that the mean allowable concentration for trichloracetic acid should be fixed below 96 mg./l.

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Conference of the British Occupational Hygiene Society on Radiation Hazards in Industry

The third conference of the British Occupational Hygiene Society was held at the London School of Hygiene and Tropical Medicine on November 1, 1954. The President of the Society, Professor E. J. King, was in the Chair. The following papers were read at the conference, and the discussion after each is also presented.

THE HEALTH OF WORKERS EXPOSED TO IONIZING RADIATIONS

BY

A. S. McLEAN

From the Industrial Group of the United Kingdom Atomic Energy Authority

When we consider radioactivity as an occupational health problem we are seldom, if ever, concerned with the consequences of massive doses of radiation. Although much is known about these acute effects, this knowledge is of little assistance when we attempt to weigh up the hazards of radiation work. However, we can turn to an impressive list of patients who have been injured by prolonged and relatively low-level exposure of one sort and another and there is much to be learned from the fate of these unfortunate people.

First and foremost on this list must come the uranium ore miners of Schneeberg in Saxony and Joachimsthal in Bohemia in whom cancer of the lung has long been recognized as an occupational disease. It seems likely that the main aetiological factor in these cases was irradiation of the bronchi and lungs by the radium and its products of decay which are to be found together with uranium in the dust of uranium mines.

There are those who swallowed or inhaled minute amounts of radium and mesothorium in painting instrument dials with self-luminous paints during the first world war and in the 1920s. It was customary for these workers, mainly girls, to point the tips of their brushes with the lips. These cases occurred in America and they have been studied there with customary intensity and, as a result, we now have a clear picture of chronic radium poisoning, affecting, as it does, the blood-forming tissues and bones in particular.

More recently, further information about the effects of rather smaller doses of radium has come from the study of a number of cases which were given radium by the medical profession 20 or 30 years ago in the treatment of high blood pressure and other conditions. These cases have thrown more light upon the delicate intermediate bone changes which precede the more serious and highly malignant growths which were an outstanding feature of the luminous-dial painters. At the last meeting of the Society you heard how this sort of information has been used to estimate maximum permissible levels of radiation, and many of the figures for maximum permissible levels in current use have been derived either directly or indirectly from observations made on the group of luminous-dial painters.

Many of the pioneer radiographers and radiologists sustained injuries of the skin and of the blood-forming tissues. A few years ago it was shown that in America the incidence of leukaemia used to be about nine times greater in radiologists than in the remainder of the medical profession.

Even more recently a number of cases of damage to internal organs have been shown to be due to thorium compounds, including "thorotrast".

These and other observations on human beings have, of course, been corroborated and extended by experimental work with animals, but there is the ever-present difficulty in the application to one species of knowledge gained about another.

From all of these sources of information it is possible to build up a sketch of radiation pathology.

(1) Damage of the blood-forming tissues may be shown by a variety of changes ranging from a reversible diminution in the number of white blood cells to aplastic anaemia and leukaemia, both of which must be regarded as fatal conditions.

(2) There may be a number of degenerative changes in the skin, including chronic dermatitis, nail distortion, wart formation, and malignant disease.

(3) The lens of the eye may show cataract formation.

(4) Impaired fertility may be the result of damage of the gonads.

(5) Radioactive substances deposited in bone may eventually cause peculiar forms of degeneration and malignant disease.

(6) Cancer of the lung may result from the deposition in the lungs of an insoluble radioactive substance.

(7) Radiation appears to be capable of some subtle influence upon the genes, those delicate custodians of our immortality. No effect could be more vital and the full weight of radiobiological research is now being brought to bear upon this problem. In this context, we are thinking, of course, of large populations not of individuals.

A further fact which emerges from these observations is that the susceptibility of any tissue of the body to the damaging effects of irradiation is a function of the state of cellular activity in that tissue. Thus, when all tissues are irradiated equally, the highly active blood-forming and reproductive tissues are more easily injured than, for example, the nerve tissues. Nevertheless, a less sensitive tissue may alone be damaged when it is the site of selective deposition of a radioactive substance in the body.

In this way it is possible to differentiate between two distinct processes which may operate in the production of radiation injury. Damage may result either from the irradiation of whole or part of the body from an outside source or from the irradiation of selected organs after the uptake of a radioactive substance into the body.

In the examples which have already been given, injuries of the blood-forming tissues, skin, eye, and gonads have generally resulted from external irradiation, whereas diseases of bone and lung are examples of damage following assimilation of a radioactive substance. In the latter case, modes of entry into the body are of special interest and it is clear that uptake by inhalation presents the most serious problem because of the high rate of retention and absorption in the lungs. Nevertheless, the risk of internal contamination by swallowing cannot be neglected, and, just because the hands come into contact so often with the mouth and nose, quite unexpected difficulties may arise. The danger of uptake through skin wounds is of special importance in laboratory operations, for example, where glassware is handled. Following uptake into the body, each element will follow a characteristic pathway which is a function of its chemical properties. Iodine, for example, will concentrate in the thyroid gland, whereas many of the heavy metals, *e.g.*, radium, plutonium, are deposited selectively in bone and are known as " bone seekers ".

Before discussing the methods of radiation protection it is necessary to refer again to the small but measurable quantities of radiation which are a part of our environment. It is interesting to divide these into unavoidable and " man-made " sources. In the former category are cosmic radiation and the emissions of naturally occurring radioactive substances such as potassium 40, carbon 14, radon, and uranium. In the " man-made " category are the *x* and gamma rays used for diagnostic and therapeutic purposes and, unfortunately, for shoe-fitting, the radiation from luminous-dial watches and clocks, and from projection television, and the substantial rise in the natural radioactivity of the atmosphere during smog. Thus, it is clearly impossible to achieve zero concentration in radiation work and we believe that the appropriate maximum permissible levels are both safe and realistic. Certainly, the minimum damaging dose, in terms of the list of injuries I have already given, is considerably greater than the maximum permissible level. It has been accepted that tiny doses of radiation are of minor significance, and " radiation work " has therefore been defined as work involving regular exposure in excess of one-tenth of the maximum permissible level.

There is a perfectly logical sequence of methods by which the hazards of radiation may be confined within tolerable limits, but all of these are dependent upon sound design and planning of operations. For example, in a situation involving an external radiation hazard, the design engineer makes use of radiation-absorbing materials which are placed between the radioactive source and the worker ; in planning remotely controlled operations he will perhaps use his knowledge that a considerable amount of radiation is absorbed in air ; again he may design so as to avoid continuous exposure of any one operator. But much of what is designed into a plant in the way of safety must ultimately become the springboard of the plant manager, for it

is he who has to quicken and live with the brain-child of the designer. One feature of particular interest has been the development of methods of enclosure and ventilation of the very high efficiency necessary to avoid even minute degrees of contamination.

The training of radiation workers has demanded special attention : in some cases it has been necessary to allay fears arising from the unpleasant associations of radiation with atomic bombs ; in others there has been some difficulty in convincing workers of the existence of a hazard which cannot be appreciated by any of the senses. In all cases it has been our aim to present radiation hazards in perspective. Of no less importance has been the dissemination of as much information as possible among the many people who live in the vicinity of our establishments or may have special reasons to contemplate the hazards of radioactivity. It appears that there is a pressing need for popular acceptance of the slight hazard of atomic energy along with its great benefits.

Measurement of radiation hazards, or " monitoring ", as it is called, differs from such detection elsewhere in one essential ; the maximum permissible levels of radiation and the quantities which can be measured by modern instruments are minute by any comparison. For example, the maximum permissible level for plutonium in air is only a few millionths of a millionth of a gram per cubic metre (less than one-millionth of the comparable figure for lead) and this amount can be measured quite easily. Health physics is a new, exact, and elaborate science, and the health physicist has come into his own as a fully fledged specialist. The responsibilities of the health physicist and the medical officer are, of course, closely related, and the monitoring of the environment and of the outside and the inside of the worker himself are regarded as complementary.

Of special interest to the medical officer, however, is the monitoring of the excreta for traces of radioactive contamination. In the case of plutonium, for example, the maximum permissible body content is six-tenths of a microgram. The body content is usually estimated from the amount excreted each day in the urine and this requires the analytical chemist to separate and measure a few micromicrograms of plutonium from, say, 1½ litres of urine containing 60 or 70 grams of total solids.

The protection of the individual worker may require the use of a variety of types of protective clothing and breathing apparatus, many of which are conventional, although some have been developed to meet special requirements.

From the start, the atomic energy industry has provided health physics and medical services at each establishment. The medical profession is expected to contribute by providing expert advice about occupational and public health risks and about the measures necessary to reduce them to inocuous or tolerable levels. Conventional methods are used in a variety of clinical and laboratory examinations and in the provision of treatment for casualties. Less ordinary techniques have been developed to deal with the problems of radioactive contamination of the skin and of the inside of the body. As a matter of good industrial health practice and in view of the long latent periods involved in the production of radiation injuries, it is important that the story of the health of radiation workers should be kept in the form of detailed records.

These are the principal techniques of radiation protection. The extent to which any or all of them may be required will depend upon the type and quantity of radiation or radioactive substance handled and upon the method of its application. Radiation protection accounts for a substantial part of the cost of atomic energy development, yet the price is paid ungrudgingly, although thoughtfully, for we are convinced of the great benefits that are in store for mankind.

Discussion

Dr. E. F. EDSON (Pest Control, Cambridge) said that the author had dealt with the general principles by which radiation protection could be attained in a large organization such as the United Kingdom Atomic Energy Authority. At the present time, small though very important quantities of radioactive substances were being used in laboratories, in industry, in hospitals, and in research institutions. The same problem of protection, but on a smaller scale, must arise in these small units. One of the functions of the Society, therefore, must be to spread the gospel of protection.

There were three main points of which one had to be constantly aware. The first was the intrinsic danger of the material being handled ; with chemicals it was acute, subacute, or chronic toxicity. With radiochemicals it was their capacity to produce radiation injury to the cells. The second was the habits of the worker. It must not be forgotten that most workers, and indeed almost everybody, if not effectively supervised, tended to be somewhat dirty in their methods of work. With that must be linked the dirtiness of the equipment which the management provided for the worker. The third was the duration of the exposure. Those conditions he represented in the formula $D \times D \times D$—the dangers of the material or job, the dirtiness of the methods applied, and the duration for which the individual worker was exposed.

He asked Dr. McLean to say something more about medical diagnosis and treatment. No matter how well the planning was done, casualties did occur in the laboratory, the factory, and the home.

He also asked Dr. McLean to explain what measures could be taken to determine that a worker had had in fact too much radiation or had absorbed too much radioactive substance, and how over-exposure should be treated.

In reply Dr. McLEAN said that because the maximum permissible levels were set considerably below the minimum damaging levels and because, also, of the very long latent periods involved in the production of radiation effects, the use of clinical tests to diagnose small degrees of over-exposure was not likely to be very helpful. The whole basis of diagnosis of slight total body over-exposure was physical rather than chemical and would be discussed in detail in other papers.

The clinical tests, which might be regarded as complementary to the physical tests for total body exposure, would be the examination of the number and distribution of the white blood cells in the circulating blood. This was not a sensitive test. There was an international agreement that where the average radiation exposure was less than one-third of the maximum permissible, it was most unlikely that examination of the blood would yield any useful information.

A blood count as a routine tool in radiation protection was very much in decline. This view was supplied by Mr. D. G. ARNOTT, of the London Hospital, from his experience of protecting hospital workers. At the London Hospital they did a blood count before exposure but afterwards relied on physical methods.

For internal contamination Dr. McLEANS aid that the most accurate measure of what a man had absorbed was generally the estimate of the total body content made on the basis of the amount excreted in the urine. Where the radioactive material gave out a high penetration gamma radiation, as radium does, this might be measured directly by an arrangement of ionization chambers round the body of the worker.

The treatment of over-exposure was of interest, perhaps particularly to those concerned with civil defence arrangements. The biological effects of radiation on mammalian tissues were so generalized that no one drug could be expected to provide the answer, unless it was aimed at counteracting the fundamental mechanism by which radiation produced its effect on tissue.

The sort of things which had been investigated for treating external radiation over-exposures were anaesthetics, sedatives, antibiotics, autonomic drugs, blood and blood derivatives, derivatives of the reticulo-endothelial system, hormones, alcohol, pyrogens and antipyretics, and physical methods such as variations in oxygen tension, particularly the effect of anoxia, variations in the temperature and the metabolic rate of the animal, and shielding of various portions of the body. The major conclusion arising from these investigations was that there were widespread differences of opinion about the possible usefulness of almost all these materials and methods. The only really useful method of treating radiation injury seemed to be a combination of antibiotics with certain blood derivatives. In the search for a substance which might be expected to influence the fundamental action of radiation on tissues, a promising approach had recently been suggested through investigating the relationship which appeared to exist between radio-sensitivity and the phagocytic functions of the cells of the reticulo-endothelial system.

With internal radiation it was necessary to interfere with the deposition of radiaoctive materials in tissues, to displace them from tissues, and to enhance the excretion rate. Metal displacement therapy with zirconium, for instance, had been tried and had been slightly effective in certain cases. Ethylenediamine tetracetic acid and its calcium disodium salt had been investigated thoroughly and was to some extent effective for contamination with certain elements such as yitrium, and one in much more common use, lead, but it was much less effective for plutonium and radium.

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RADIATION SAFETY AT AN ATOMIC ENERGY FACTORY

BY

D. R. R. FAIR

From the Department of Atomic Energy, Windscale Works, Sellafield

Many people still think of atomic energy as a matter of scientists with scientific assistants and laboratories with laboratory-type equipment. The factories of the Industrial Group of the U.K. Atomic Energy Authority are controlled and directed by engineers and industrial chemists as well as by physicists, most of whom must be as skilled in management as they are in the technical complexities of their work. The employees are process workers of various grades and skilled tradesmen such as fitters, electricians, and instrument mechanics.

When we are thinking of radiation protection we are thinking mainly of workpeople in factories and not of scientists in laboratories.

External Radiation

To achieve safe working conditions in a factory operating nuclear piles or chemical plants which separate the plutonium, uranium, and fission products formed in the piles, certain data are necessary. First, the magnitude and spatial distribution of the sources of radiation ; second, the type and energy of the radiations emitted by the sources ; third, the variation of both of these with time, for example, with the age and operational state of a pile or with the stage reached in a chemical flow sheet ; fourth, technical information regarding the types of shielding available, their effectiveness and cost, and the so-called " maximum permissible levels " for the various radiations concerned.

With this data the design staff select the best and most economical material to build the shield around the plant. Gamma rays are stopped most easily by heavy metals like lead, but lead is expensive and it is often cheaper to put up a thick shield of concrete than a thinner shield of lead. To screen a neutron source it is necessary to surround it by a material which will slow neutrons down. (The mechanism of the absorption process is different from that applying to gamma rays.) A good slowing-down medium for neutrons must be made up of light atoms. Concrete, containing as it does a great deal of hydrogen, is a better shielding material for neutrons than lead or iron. Concrete is in fact very useful for shielding purposes because, provided the composition and thickness are properly chosen, it is efficient, cheap, and an excellent building material.

The determination of shield thickness often requires very elaborate calculations but practical experience of shielding large radiation sources is, of course, now available to the industry. Not all shielding is concrete. Water is often an excellent shield since it also permits underwater manipulation of the active material.

It is not always necessary or desirable to shield parts of plant or equipment. The early assessment of the external radiation hazard associated with chemical plant which has carried highly or medium active liquors was such that it was thought either to be impossible or at best extremely difficult and costly to carry out maintenance operations on such plant at all. This had a profound influence on the design of the plant. Considerable ingenuity and inventiveness were exercised to avoid putting items which required maintenance behind biological shields. Also the method of access to the plant and equipment behind the shields was not considered in detail since it was thought that no one would be able to go behind the shields once the plant had become active. In fact the early estimates of radiation levels were not substantially incorrect but the extent to which it would be possible to control work in high-radiation fields so that the worker was not exposed to a radiation dose greater than the permissible was underestimated. It has now been found possible to undertake maintenance and modification work on active plant, and it is important that such work should not be made more difficult and dangerous to the maintenance man because of shielding placed to safeguard the plant operator. The design should not be distorted to accommodate a shield if safety may be achieved for the plant operators by distance. In many cases, the hazards from radiation decrease roughly as the square of the distance. For safety by distance to be effective with the high-radiation fields met with in the atomic energy industry the method of entry to the dangerous areas must be controlled as strictly as the entry to high-voltage areas in an electrical distribution system.

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It is not always necessary or desirable to shield parts of plant or equipment. The early assessment of the external radiation hazard associated with chemical plant which has carried highly or medium active liquors was such that it was thought either to be impossible or at best extremely difficult and costly to carry out maintenance operations on such plant at all. This had a profound influence on the design of the plant. Considerable ingenuity and inventiveness were exercised to avoid putting items which required maintenance behind biological shields. Also the method of access to the plant and equipment behind the shields was not considered in detail since it was thought that no one would be able to go behind the shields once the plant had become active. In fact the early estimates of radiation levels were not substantially incorrect but the extent to which it would be possible to control work in high-radiation fields so that the worker was not exposed to a radiation dose greater than the permissible was underestimated. It has now been found possible to undertake maintenance and modification work on active plant, and it is important that such work should not be made more difficult and dangerous to the maintenance man because of shielding placed to safeguard the plant operator. The design should not be distorted to accommodate a shield if safety may be achieved for the plant operators by distance. In many cases, the hazards from radiation decrease roughly as the square of the distance. For safety by distance to be effective with the high-radiation fields met with in the atomic energy industry the method of entry to the dangerous areas must be controlled as strictly as the entry to high-voltage areas in an electrical distribution system.

Safety by shielding and safety by distance are contributions to the workers' safety from external radiation which are made by the design officers.

Plant and equipment designed for radioactive materials do not differ from other plant in that they do from time to time require either maintenance or modification and it is during such work that the factory management is faced with its greatest problems of control. The questions to be answered before beginning work in a very high radiation field of, say, 10 to 10,000 times the maximum permissible level are :—

(1) Is anything to be gained by waiting? This is always an unpopular thing to do in a factory. In certain cases where the radioactivity is due to fresh fission products a safety factor of 10 or more is gained in 24 hours by allowing the short-lived of the fission products to decay completely before beginning work.

(2) Is it possible to reduce the radiation field? For example, if it is due to fission products inside vessels or pipework, decontamination may be both possible and worthwhile.

(3) What is the radiation dose-rate in and around the area where work is to be done? A survey of both beta and gamma radiations is carried out to give this data.

(4) Is it possible to erect temporary radiation shields around high centres of activity or around the immediate working location? The answer to this question is generally delicately balanced and depends upon the probable length of the work to be done, the intensity of the field, the ease with which a shield may be provided, since it must not be forgotten that men will have to erect the shield, and the influence of a shield on the work to be done. In certain locations where space is very limited a shield might so impede the maintenance man that his radiation exposure is actually increased because of the extra time needed to do the job.

(5) Are special tools necessary for remote handling of the plant or equipment? Again the answer to this question is often delicately balanced and depends upon the beta radiation present as well as the gamma, since if the beta level is high this will constitute an additional hazard to the hands. It is often thought that thick gloves give complete beta protection, but this is not necessarily true and in any case many tasks demand manual dexterity and a good sense of feel, so that, although gloves are worn, they are often thin and well fitting—rather like surgeons' gloves.

When the method of working and permissible working time per man have been determined, then the man himself is briefed, radiation monitoring films are placed on his body, wrist, and cap, and he will carry also a pocket dosimeter, which gives a direct reading of the dose received. The man's entrance to the radiation area will be timed and he will be recalled from the job by a man specially detailed to control working times.

The men have been trained in simple procedures to reduce radiation exposure; discussion of the next step to be taken should not take place right on the job but away from it in a low-radiation field; a mate should not stand at the craftman's shoulder unless there is a task to do.

By these commonsense methods, work in high-radiation fields has been carried out successfully without over-exposing the workers.

Internal Radiation

The problems associated with the protection of the workers in the atomic energy industry from the inhalation or ingestion of radioactive materials have been amongst the most difficult the industry has had to tackle.

The problem itself is not new in principle; it is new only in degree. The maximum permissible concentration (m.p.c.) or maximum allowable concentration (m.a.c.), or "design concentration", to use the terminology suggested by Dr. Goldblatt at our last conference, of plutonium in air is 32 micro-micrograms per cubic metre of air, and it is this tiny quantity of the industry's product that must not be exceeded in the working space. As well as this level for plutonium there are similar or lower levels for fission products such as strontium and iodine, which are waste-products of the industry. As for external radiation the solution is a combination of good design and good management. Radioactive material can escape into the air only when pipework or vessels are vented to air or leak or when it is necessary to transfer material from one vessel to another. The design officers provided the main chemical plant buildings with a high stack so that any radioactive material arising from vented vessels and not removed by a scrubbing system would be so diluted before it diffused to ground level that it would be quite harmless. Also in the main chemical separation plant the columns, tanks, feed pipes, and so on were fabricated from stainless steel and welded together. A special corrosion-resistant stainless steel was developed to meet this requirement, and the technique of welding stainless steel had to be further developed to deal with the type of steel used and the very high standard of welding demanded. It was not possible, however, for the designers to provide an all-welded construction in plants fed from the main chemical separation plant and neither

was it possible to avoid taking liquor out of plant for transfer or temporary storage at certain stages. Liquor transfer becomes progressively more difficult as the transfer takes place later and later in the plutonium production process; that is, with stronger and stronger plutonium solutions. One method of transfer is to use a hypodermic needle technique for filling and emptying containers covered with specially well fitting rubber caps. However, the small quantity of plutonium needed to give rise to an m.p.c. in air is such that even the hypodermic technique cannot be carried out in the open but must be done in a specially ventilated enclosure. The vessels are therefore normally raised on to the needle rather than the needle inserted into the cap of the vessel, and this operation is done remotely. It is by such methods as these that air contamination during normal process operations has been kept under control. However, plant needs modification or maintenance, and if work is to be carried out on active plant air contamination is generally bound to arise. The exception is when the plant or items concerned can be completely decontaminated before remedial work starts, but even then air contamination is caused more often than not when the item is removed for decontamination.

The air contamination is reduced by carefully cleaning out the vessels and pipes before opening them and by arranging the work in a precise sequence so that messy or dusty actions or movements are avoided. Careful briefing of the craftsmen in procedure is necessary. Also the point where the break into the active system is made is sprayed with a solution of glycerine in water to lay any dust as soon as it becomes airborne. The glycerine is hygroscopic and prevents the water evaporating too quickly. Considerable use is made of absorbent paper shrouds placed around the necks of vessels and under pipes to facilitate the subsequent cleaning up. The volume of air which is contaminated is carefully defined by building around the work to be carried out a tent-like enclosure made of tubular steel framework and polyvinyl chloride sheet, the joins of which are sealed by a cocooning process similar to that used by the Services to encase military equipment. The contaminated air is exhausted from the tent enclosure through a high-efficiency vacuum cleaner and is then fed into one of the air-trunking systems connected to the stacks. It is fortunate that as the plutonium concentration increases and the careful enclosure of active work becomes more and more necessary, so the beta-gamma content of the solution becomes less and less and the external radiation hazard decreases, thereby making the erection of the enclosures possible.

To provide the worker with clean air one of three methods is followed. A dust respirator fitted with a Porton dust filter type D8/42 is worn. The filter is designed to permit no more than 0·00001% penetration for $\frac{1}{2}$ micron size particles, but the real limitation is the fit of the respirator to the man's face. When the air contamination is very high or toxic gases may be present in quantity—many of the plants have an installed carbon-dioxide fire-fighting system—then clean air must be provided for the worker rather than reliance placed upon filtered air. If the job is of short duration of up to 20 min. or great mobility is needed, then the worker carries an air bottle on his back. The fireman's "self-air" apparatus is the one in use. If the job is a larger one the worker has an airline mask fed from a filtered off-take from the factory's compressed air main or is dressed in a pressurized suit which has been developed for this type of work. The pressurized suit is made of all-welded polyvinyl chloride sheet and totally encloses its wearer. The head is in a transparent polyvinyl chloride helmet and the air supply is fed in near the neck of the helmet. The air is exhausted from the suit via a filter which both prevents back diffusion of activity into the suit and provides a pressure drop to keep the suit inflated and held just comfortably off the wearer's body.

Not only is it necessary to take these precautions during maintenance or modification work, but also it is most important to clean up completely after the operation so that any contamination left is below a level which could give rise to an ingestion or inhalation hazard. Permissible surface contamination has been set at such levels that it is believed that working for a full working lifetime with such levels on floors, benches, walls, plant, equipment, and so on, will not be injurious to the individual exposed. Detailed surface contamination surveys follow work on active plant and are part of normal routine. The worker is dressed according to the task he has to tackle. He will wear a simple coverall over his own clothes for most normal process work in the chemical plant, and will be progressively clothed as the hazard increases until he is dressed from the skin up in factory clothing and enveloped in a P.V.C. suit for the most difficult job. Undressing a man who has been in contact with active materials is a potent source of air and surface contamination, and undressers with dust respirators have been trained to do this. The wearer of a pressurized suit often has to pass through a water shower followed by a shower containing both wetting and complexing agents before removing his suit.

Just as detailed, surface-contamination surveys

are part of every day's work, so are careful surveys of contamination of the workers. There are three stages by which workers are examined for contamination: (1) Monitoring of the individual with portable equipment on the job: this is to locate contamination as soon as it arises. As with any other form of dirt, contamination is most easily removed if cleaning is undertaken quickly; also, monitoring on the job, as well as protecting the worker concerned, protects also his workmates and the rest of the plant, since it is very easy to transfer contamination from one place to another. (2) Monitoring of the individual with installed equipment before he leaves a building: this, again, is to protect the worker and also the plant. Cross-contamination of two plants dealing with uranium and plutonium, for example, would lead to the adoption of the plutonium design concentration in the uranium plant, since it is not possible to say quickly whether alpha air contamination is due to alpha particles from uranium or alpha particles from plutonium. Cross-contamination must therefore be avoided. (3) Monitoring of the individual with installed equipment before he leaves the factory: the worker has to wash at least his hands and may have to shower if he has undertaken certain tasks. After washing he presents his hands to a machine and a bell rings if they are contaminated.

Before leaving the subject of ingestion and inhalation control, mention must be made of certain areas of the plant where small laboratory-type operations are carried out and also of the control laboratories where process-line samples are analysed and assessed. In each of these areas a new factor other than the health of the worker exerts a controlling influence: in the plant it is the purity of the product, and in the laboratory it is the necessity to maintain a low radioactivity background to enable accurate measurements on low-activity samples to be made. Operations are carried out in perspex-fronted boxes which are sealed from the working space and maintained at a negative pressure to it. Materials and samples are posted into the box through an air lock and manipulation of the equipment is carried out through long gloves which are sealed to holes cut in the perspex front.

Detection and Measurement of Hazards

Before it can be hoped fully to control a hazard quantitative determination of the hazardous materials must be made. The measurement of radioactive hazards with certain exceptions are not unduly difficult.

The simplest monitor makes use of the effect by which radioactivity was discovered in 1896, namely the blackening of a photographic film. Beta-gamma radiation survey instruments and beta-gamma surface contamination instruments both use the ionization of a gas in a closed space. In the former the net electrical charge resulting from the ionization is collected by a metal electrode in the ionization chamber and the current is measured directly by a sensitive electrometer or more usually after amplification. In the latter, that is, in most contamination-monitoring instruments, the ionization is used to trigger off bigger electrical discharges which are then counted electronically. This is the Geiger–Muller effect. In the ionization chamber the ionization current will depend upon the energy of the radiation whereas in the contamination monitor, dependent upon the Geiger–Muller effect, the method is independent of the energy of the radiation provided it exceeds the minimum necessary to trigger off the discharge. Alpha surface contamination is measured by the same method, in principle, as that used originally by Rutherford and his co-workers. The scintillations caused by alpha particles falling on a zinc sulphide screen are viewed electronically, that is, with a photomultiplier tube, and the resulting electric impulses from the tube are counted by electronic counters. The zinc sulphide screen must be protected from light and is therefore enclosed in a light-tight box, one side of which is closed by an aluminized nylon foil. It is this foil which makes this instrument difficult to keep serviceable since the foil must be so thin that it will not stop an alpha particle and yet sufficiently robust to remain light-tight even when used in a factory. Air contamination is measured by taking large-volume air samples of the order of five to 25 cubic metres per hour. The air is drawn through a Whatman filter paper by a modified vacuum cleaner unit and the volume is measured by an anemometer. The filter paper, with the airborne radioactivity now deposited upon it, is presented to beta-gamma and alpha counting equipments working on the same principles as those described earlier. The activity measured is corrected for the counter efficiency, the self-absorption of the activity in the filter paper, and the filter paper efficiency, when this is necessary.

The development of laboratory tools into factory survey instruments has been the responsibility of the Atomic Energy Research Establishment at Harwell.

Surveys

A very large number of radiation, surface contamination, and air contamination surveys have to be made every day. It was decided to select and train a group of process workers to set up, calibrate, and operate radiation-monitoring instruments. The

process workers, called health physics monitors, have carried out most successfully a very heavy programme of surveys over the last few years. They also interpret to the engineering and production sides the results of their surveys as long as " rule-of-thumb " interpretation is possible. The factory has laid down a series of contamination levels both air and surface and has specified what action is to be taken at each level. The work of the surveyors is controlled by a physicist and interpretation of a survey which is beyond the " rule-of-thumb " category is made by him.

Plutonium Air Contamination

The detection of plutonium contamination is a particularly difficult matter. The design concentration may be expressed as a quantity of plutonium which will give about 10 d.p.m./m.^{3} of air. Unfortunately the air contains naturally the daughter-products of both radon and thoron and amongst the isotopes in the Ra A, B, C, C′, C″, and D chain and the similar thorium chain are alpha emitters. The concentration of radon and thoron decay products varies widely from day to day but is in the range of 5 to 500 d.p.m./m.^{3} of air. Therein lies the problem ; when an air sample is taken, and the alpha activity counted, the plant man requires to know at once if there is any plutonium present. The physicist is unable to do an immediate identification of the alpha activity. Two ways are open to him : first, to measure the alpha energy by an alpha energy discrimination of some sort, but this is a laboratory tool and not a factory survey instrument. In any case it is time consuming. Second, to measure the variation of activity on the filter paper with time. If it is plutonium no decay will occur since plutonium has a half-life of 25,000 years. If it is the decay products of radon and thoron then within one hour measurable decay will have occurred. But the plant man has had to wait for an hour and even then the sample tells him only of conditions an hour ago. Out of this unpromising position an operational procedure has been devised which has worked most satisfactorily.

Although the natural background varies both with time and with place, it is unusual to find it widely different at different places on the same factory site at the same time. So the evidence from one part of the plant is used to help to judge conditions in other parts. If the level is less than 10 d.p.m./m.^{3} then no action is required to identify the alpha activity since it is below a design concentration even if it is plutonium. If the level exceeds what is generally judged to be the area background activity at the time by 100 d.p.m./m.^{3} or more, that is, by more than 10 times the design concentration, then safety precautions are immediately instituted. Dust respirators are worn and active measures instituted to locate the contamination source if this is not known or already suspected. If the level exceeds what is generally judged to be the area background activity at the time by more than 10 d.p.m./m.^{3} but less than 100 d.p.m./m.^{3}, that is, by more than one design concentration but less than 10 design concentrations, then safety precautions are brought to readiness, all possible sources of air contamination are checked and a second determination of the activity of the sample is made 30 min. after the first determination. The extent of the decay enables a judgment to be made whether the sample does or does not contain plutonium. In any case a second sample is started immediately the first one is taken off, so during the 30 minutes' decay of the first sample the second sample is taken and assessed and that too helps in assessing the position.

At the present time the Atomic Energy Research Establishment at Harwell are working on new alpha-measuring instruments which, it is hoped, will improve the position still further. One such instrument prints the alpha activity in the working space on a recorder and side by side with this prints the alpha activity in air drawn from outside the building. A direct comparison between the two is thus possible.

Safety Control in the Factories

A department independent of both the production and engineering sides of the factory has been set up with its head answerable to the works general manager. This department, the Health Physics Department, is responsible for carrying out all the radiation, surface contamination, and air contamination surveys in the factory. As each survey is completed a copy is handed direct to the plant supervisor with recommendations for action where appropriate. The surveyors or health physics monitors are encouraged to work as additional members of the production and engineering team. Safety is not achieved by policemen but by the willing and full cooperation of those whom one seeks to make safe.

The head of the Health Physics Department has also been made responsible for the normal factory safety under the Factories Act and the works safety officer answers to him. This has provided an excellent and most salutary lesson to the physicists in charge of the department. They have found that accident prevention follows four well-tried paths : (1) to remove the hazard ; (2) to shield the hazard ; (3) to shield the worker ; (4) to warn the

worker. The principles necessary to achieve radiation safety are no different. It is very easy when tackling a new problem, such as radiation safety in industry, to think that it is new in principle, but responsibility for industrial safety has taught that it is not so. Safety in the atomic energy field is achieved, as safety is achieved in other industries, by a combination of "design for safety" by the design offices and "manage for safety" by the works management.

Discussion

Dr. A. NEMET (Philips Balham Works Ltd.) said that medical and industrial *x*-ray workers had learned to protect themselves from external radiation and, in industrial work at least, this could be done without any detriment to the quality of the work. The medical man, however, lived in a constant struggle between his natural wish to see more of the *x*-ray screen and his prudence in protecting himself with clumsy lead-rubber aprons and gloves, which hampered him. Without that protection the radiologist would suffer the maximum permissible dose, due to scatter from his own patient, in a single morning in an average hospital doing barium meals only. There seemed to be no doubt that atomic factory workers were safer from that kind of hazard than the average hospital radiologist or radiographer.

The two other hazards, airborne dust and ingestion, were of quite a different order, partly because the tolerance levels were so very low and were still getting steadily lower due to advances in biological research, but also because it appeared to be so difficult to protect the worker against carelessness.

The most serious risk was inhaled radioactive dust, because in measuring this type of contamination it was necessary to compensate for the harmless background radiation which, as Mr. Fair had said, might be one hundred times higher than the maximum permissible level of plutonium.

Something which Mr. Fair had not pointed out, but which was really the limiting factor, was the statistical fluctuation of both the background and the contamination. As, in addition, the background varied by as much as 30–1, it became clear that it was impossible to record airborne activity instantaneously; the collection of dust and the counting must take a long time in order to gather sufficient counts so that the desired accuracy of, say, 10% was obtained.

Another practical difficulty with particle-borne radiation was to make reasonably certain that the sampled air was really representative of the background and the suspect channels of the air breathed.

Mr. D. R. R. FAIR, in reply, said that the position was very different from that which existed in hospitals and laboratories, where it was necessary to depend on the individual himself; in factories there was factory discipline.

The alpha air contamination problem was the most difficult. In any one area or factory site there was a large number of air samplers operating at the same time, which made it possible to judge one particular location in the light of others. Moreover, in a process plant one hoped to be doing tomorrow the same as one was doing today. Many members of the audience were research workers, development workers, or associated with that kind of activity, and they were always hoping to be doing something new, but they should remember that the aim of the man responsible for production was to operate his plant on a steady basis. That fact helped considerably in locating trouble, because the plant was instrumented throughout and, if there was any likelihood of air contamination, it was very seldom necessary to look for it; the man in charge of the plant almost always knew of any minor change in operating conditions likely to give rise to air contamination.

In reply to other questions, Mr. FAIR said that perspex was used for equipment and appliances because it was unbreakable. Neither perspex nor polyvinyl chloride was damaged at the ordinary radiation levels to which man might be exposed.

As their knowledge grew, it was possible to relax safety precautions. This had been done without causing any alarm to the workers by explanation and by discussion of the Joint Factory Council.

Mr. FAIR thought Dr. EDSON'S comment was reasonable in that it was too early to say that all occupational hazards had been confronted since incubation of diseases induced by radiation ranged from three to 40 years.

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BY

W. BINKS

From the Radiological Protection Service (Ministry of Health and Medical Research Council)

The purpose of this contribution is to present a summary of available information and procedures regarding the protection of radiological workers against *x* rays and gamma rays emitted by sources external to the body. In this way it is hoped to assist those responsible for the planning and designing of industrial radiological departments to provide adequate and, at the same time, economical protective measures.

Maximum Permissible Doses of Radiation

Although it may be assumed that any ionizing radiation above the " natural " level to which human beings are always subjected may be deleterious, evidence on radiation effects has indicated that, for each type of radiation, it is possible to choose a practical average level to which a radiological worker may be exposed, with negligible risk, throughout his working life. The average level so chosen is referred to as the " maximum permissible weekly dose."

According to the recommendations of the International Commission on Radiological Units (1954), " absorbed dose "—or amount of energy imparted to matter by ionizing particles per unit mass of irradiated material at the place of interest—shall be expressed in terms of the " rad ", which has the value of 100 ergs per gram. But for *x* rays and gamma rays of quantum energy up to 3 MeV, the röntgen (r) may be used. Accepting this proposal, the International Commission on Radiological Protection, 1954 (I.C.R.P.), recommends that the basic maximum permissible dose (m.p.d.) for exposure of the whole body to radiation expressible in röntgens is 0·3 per week in the blood-forming organs, eyes, and gonads. For partial irradiation of the body (for example, hands and forearms, feet and ankles, head and neck), the corresponding dose is 1·5 r per week in the skin, provided that, in the case of the head and neck, the dose-rate in the lens of the eye does not exceed 0·3 r per week. On the basis of practical considerations, the m.p.d. for whole-body exposure may be modified to 0·3 r per week in air.

Physical Factors in Protective Schemes

First, it is necessary to know the total weekly dose of radiation which would be received at the point of interest in the absence of any absorbing shield. The radiation may be that received directly from an *x*-ray tube or from a gamma-ray emitting radioisotope, or indirectly from an irradiated specimen which scatters some of the radiation falling upon it. Secondly, a knowledge of the efficacy of various materials in absorbing radiations of different types is required. From a combination of these factors it is possible to assess the thickness of the absorbing shield required in any set of circumstances to reduce the dose at the point of interest to less than the maximum permissible level. In making such an assessment, allowance should be made for the maximum anticipated weekly dose.

X-ray tubes, and some radioisotope containers, intended for radiographic purposes can, by design, emit a useful beam only within a restricted cone. Accordingly, it is not justifiable on economic grounds to provide shielding on every wall of a room which is to house an *x*-ray tube or radiographic unit of the type mentioned, on the assumption that the useful beam could be directed at every wall for the entire working week, that the source is emitting radiation continuously at its maximum level (for example, that the *x*-ray tube is operated continuously at its maximum voltage and maximum rated current), and that the workers to be protected are going to be stationed in close proximity to the walls in question for their entire working lives. It should be possible to design protective arrangements more economically by taking a more realistic picture of the operating conditions, at the same time

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allowing a margin of safety for future development and expansion of the work, since it is often less expensive to incorporate additional protection during the initial building of a department than at a later stage.

Radiation from X-ray Tubes.—Manufacturers of *x*-ray tubes usually specify the radiation dose-rate (in r/min.) at 1 metre from the tubes under full loading. In a previous publication the author has given figures as a rough guide to such dose-rates for constant potential excitation (Binks, 1943). Dose-rates at other distances can be calculated, as these decrease as the square of the distance from the *x*-ray target.

Radiation from Gamma-ray Emitting Isotopes.—The dose-rates from radioisotopes which emit gamma rays are often expressed in terms of the so-called "K factor" (r/hr. per mC at 1 cm. distance). The activity of any isotope will be specified in curies by the suppliers, so that the total gamma-ray output in r/hr. at 1 cm. distance can be calculated. Table 1 lists the K factors of a few of the radioisotopes of potential use in industrial radiography. Again, the inverse square law can be applied to determine the dose-rates at other distances.

Allowable Transmission through Protective Shields.—Calculations are given below.

For Direct X rays or Gamma Rays.—The maximum transmission which is allowable for any protective shield, if it is to reduce the direct *x* rays or gamma rays to below the m.p.d., may be calculated in the following manner.

Let R = dose-rate (in r/min.) at 1 metre from radiation source.

where R = (r/min./mA at 1 metre) × (tube current in mA) for *x* rays

or $\dfrac{\text{(r/hr./mC at 1 cm.)} \times \text{(no. of mC)}}{60 \times 10^4}$ for gamma rays

t = maximum time (in minutes) of radiation exposure of worker per week.

D = distance (in metres) from radiation source to nearest point to be occupied by worker.

∴ Weekly dose at worker's position

$$= \frac{Rt}{D^2} \text{ röntgens} \quad \ldots \quad (1)$$

Percentage transmission of protective shield to reduce dose-rate to 0·3 r/week (in free air)

$$= 30\,\frac{D^2}{Rt} \quad \ldots \quad (2)$$

For Scattered X Rays or Gamma Rays.—A similar procedure may be followed for scattered radiation. In this respect it should be mentioned that the amount of scattered radiation received at any point in the neighbourhood of a scattering object is (1) roughly proportional to the area of irradiation of the object, and (2) inversely proportional to the square of the distance from the object.

TABLE 1

K FACTORS OF RADIOISOTOPES OF POTENTIAL USE IN INDUSTRIAL RADIOGRAPHY

Isotope	Half-life	Energy (MeV)	K factor (r/hr. per mC at 1 cm.)
Co^{60}	5·3 years	1·17, 1·33	13·5
$Cs^{137} + Ba^{137}$ ..	33 years	0·669	3·9
Tm^{170}	129 days	0·084 (24%)	0·08
Ta^{182}	120 days	Complex spectrum; 0·05–1·2	6·1
Ir^{192}	75 days	0·13–0·61	2·7
Ra^{226} + daughters	1590 years	0·24–2·2	8·3

If R = dose-rate (in r/min.) at 1 metre from radiation source.

t = maximum time (in minutes) of radiation exposure of worker per week.

D = distance (in metres) from radiation source to surface of irradiated object.

a = area (in sq. cm.) of field of irradiation of object.

d = distance (in metres) from scattering body to nearest point to be occupied by worker.

s = percentage scatter, at 1 metre from exposed object, in direction of working site, per 100 sq. cm. of field of irradiation.

∴ Weekly dose of scattered radiation at worker's position

$$= \frac{Rt}{D^2} \times \frac{s}{100\,d^2} \times \frac{a}{100} \text{ röntgens} \quad \ldots \quad (3)$$

Percentage transmission of protective shield to reduce dose-rate to 0·3 r/week (in free air)

$$= 3 \times 10^5\,\frac{D^2d^2}{Rtsa} \quad \ldots \quad (4)$$

At a later stage in the paper data will be presented on the amount of scattering from different materials exposed to different types of radiation.

Absorption of Radiation.—It would be well, before proceeding to examine the experimental observations concerning the absorption of *x* rays and gamma rays, to attempt a survey of the theoretical background, as this will help to appreciate the significance of the experimental data.

A photon of *x* rays or gamma rays can interact with an atom in four ways: (1) With the atomic electrons; (2) with the protons and neutrons in the nucleus; (3) with the electric field surrounding the electrically charged nuclei and electrons; and, (4) with any meson field surrounding the protons and neutrons.

The net result of any of these interactions is that the photon may surrender all its energy, or only a portion, or indeed none at all. Of these 12 possi-

bilities, some have not yet been observed, while some occur much less frequently than others.

In the main, only three processes need be considered for our present purposes. These are: (1) The photoelectric effect, in which the photon, whose energy must be greater than that of the binding energy of the atomic electron involved, transfers all its energy, in excess of this binding energy, to the electron, which is ejected from the atom; (2) the Compton effect, in which the photon interacts with an atomic electron, and transfers only part of its energy during the process, which results in the ejection of the electron and the survival of the photon, which is degraded in energy and has its direction of motion changed; (3) pair-production effect, in which the photon, whose energy must be greater than 1·02 MeV, interacts with the electric field surrounding the nucleus and atomic electrons, and surrenders the whole of its energy, leading to the creation of an electron and a positron (electron pair).

Mention should be made of a fourth process—Rayleigh scattering—in which the photon interacts with the protons and neutrons in the nucleus. But since this accounts for only a few per cent. of the total absorption for 100 kV *x* rays produced by the three main processes referred to, and becomes negligible for *x* rays above 300 kV for light elements and above 1 MV for heavy elements such as lead, no allowance for it will be made in the present study.

Photoelectric Effect.—As regards the photoelectric effect, Heitler (1936) derived a theoretical formula for the photoelectric absorption effect in the K shell of the atom. The formula does not hold for photons of energy in the relativistic range and it is grossly inaccurate for photons of energy similar to the binding energy of the electron in the K-shell. A correction factor, $f(\varepsilon)$, for the latter inaccuracy has been worked out by Stobbe (1930). From an examination of the experimental data on photoelectric absorption, Binks (1954) has shown that the following empirical relationship holds for the absorption of photons up to 500 keV in all elements

$$_e\tau = 4{\cdot}47 \times 10^{-27}.\ Z^4.\ \lambda^{3{\cdot}3}.\ f(\varepsilon) \quad \ldots . \quad (5)$$

For the relativistic range of photon energies (that is, much greater than 500 keV) a theoretical formula derived by Hall (1934, 1936) is believed to be valid.

It should be added that, in the photoelectric process, there is a " side-effect ", in that the ejection of an electron is followed by the emission of a photon of characteristic *x* rays.

Compton Effect.—This process will be examined in so far as it may appear to the observer or " detector ". The initial photon, which is assumed to be proceeding in the direction of the detector, can be regarded as surrendering all its energy to an absorber placed in its path. This energy reappears in the form of an electron and of a degraded photon. As the latter will proceed in a different direction from that of the initial photon it will now miss the detector. In other words, it appears to the detector that all the energy of the incident photon has been lost. Such will be the case with a " narrow-beam " of photons, since the degraded photons will be scattered out of the primary beam. If, however, there is a " broad-beam " of primary photons, some of which are not proceeding towards the detecting point, the detector will receive some of the degraded photons. Thus, to the detector it would appear that less energy has been removed by an absorber under " broad-beam " conditions than under " narrow-beam " conditions of irradiation.

The total Compton absorption per electron, $_e\sigma$, may be split into two components, the first, $_e\sigma_a$, relating to the energy removed by the ejected electron, and the second, $_e\sigma_s$, relating to the energy taken by the modified photon. In narrow beams the effective absorption will be $_e\sigma_a + {}_e\sigma_s$; in broad beams it will be $_e\sigma_a + f._e\sigma_s$, where $f._e\sigma_s$ represents a fraction of this component, and depends on the size of the irradiated field, the material and thickness of the absorbing layer, and the positions of the radiation source and detector relative to the absorber.

The Compton linear absorption coefficient for any element is derived from the absorption coefficient per electron by multiplying by the electron density of that element. There should, therefore, be more scattered radiation generated in, say, a lead absorber than in absorbers of the same thickness composed of light elements. There is, however, a counter-effect. As will be seen from formula (5), dealing with the photoelectric effect, absorption per electron due to this process increases as the fourth power of the atomic number and as the 3·3 power of the wave-length. Accordingly, the degraded scattered photons, which are of longer wave-length than the initial photons, will, whatever the absorbing element, undergo greater photoelectric absorption than the initial photons and will, furthermore, be subjected to very much higher photoelectric absorption in an element of high atomic number, such as lead, than in elements of low atomic number.

Pair-production Effect.—The first theoretical predictions (Bethe and Heitler, 1934) indicated that the pair-production absorption coefficient per electron should be proportional to the atomic number Z of the element. Later it was seen that the proportionality factor is nearer $Z + 1$.

Again, there is a side-effect which should be noted. The positron of an electron-pair is quickly " annihilated " for, when it encounters an atomic electron, the two combine and release energy of the order of 1·02 MeV or more, generally in the form of two photons.

Finally, it should be mentioned that, in all the processes here considered, it is possible for the electrons (or positrons), which are emitted following the interaction of the photon with the atom, to re-radiate energy as they are slowed down in the absorbing material. This type of radiation is known as *Bremsstrahlung*.

Total Absorption Coefficient.—The total absorption coefficient (expressed as the electronic, or atomic, or linear, or mass coefficient) is the sum of the photoelectric, Compton, and pair-production coefficients. Applying these coefficients, calculations have been made of the absorption, in lead and other materials, of *x* rays and gamma rays under " narrow-beam " conditions (Kaye and Binks, 1940) and of gamma rays under some selected " broad-beam " conditions (Fano 1949, 1953 ; Fano, Hurwitz, and Spencer, 1950). The calculated absorption data are in close agreement with the experimental results.

X-Ray and Gamma-Ray Absorption Data.—Certain data are now available.

X rays.—Experimental transmission curves in lead are now available for *x* rays excited at voltages between 50 and 2000 kV, for " broad-beam " conditions. For voltages between 50 and 200 kV, transmission curves are given in an earlier paper by the author (Binks, 1943), and relate to beams filtered through an *x*-ray tube window equivalent in absorption to 0·07 mm. Cu. The curves for 200 to 300 kV *x* rays, appearing in Fig. 1, are also from observations made by the author for appropriately

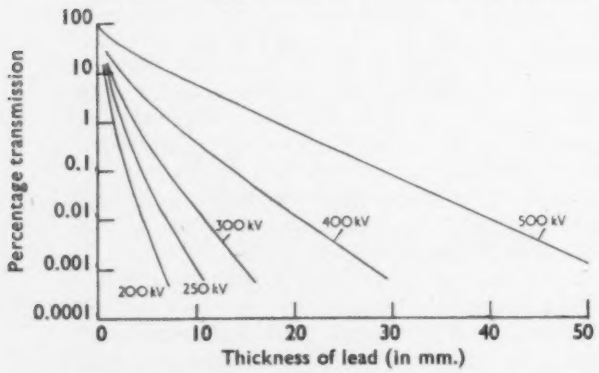

FIG. 1.—Transmission curves in lead for *x* rays excited at various constant voltages between 200 kV. and 500 kV.

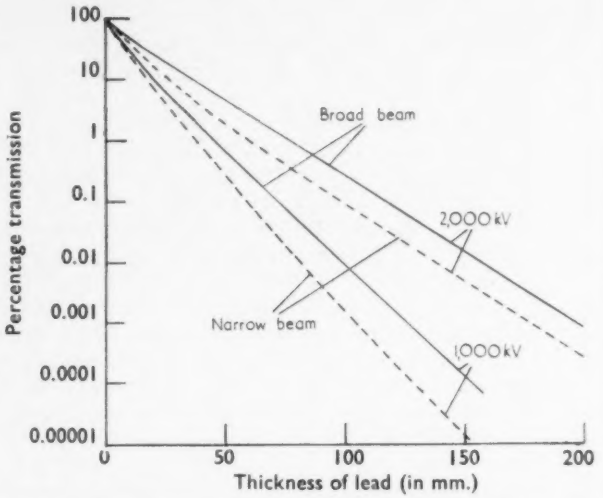

FIG. 2.—Transmission curves in lead for broad and narrow beams of *x* rays excited at constant voltages of 1000 kV. and 2000 kV.

heavier degrees of filtration, while the 500 kV curve is taken from the results of Wyckoff, Kennedy, and Bradford (1948). The 400 kV curve is one deduced by interpolation. In Fig. 2 is a broad-beam curve determined experimentally (Wyckoff, and his colleagues, 1948) for 1000 kV *x* rays which had been passed through a rather complex initial filter, composed of 2·8 mm. tungsten, 2·8 mm. copper, 2·1 mm. brass, and 18·7 mm. water. There is, also, a broad-beam curve for 2000 kV *x* rays filtered through a composite window equivalent to 6·8 mm. lead (Evans, Granke, Wright, and Trump, 1952)*. In the same figure are plotted curves based on calculations which the author has made for narrow beams of 1000 and 2000 kV *x* rays, initially filtered through the respective filters mentioned above. The ratio of the broad-beam transmission (direct plus scattered photons) to the narrow-beam transmission (direct photons only) is called the " dose build-up factor ", which is due to scattered photons. The estimated build-up factors are given in Table 2. It will be clear from this evidence that protection measures against direct *x*-radiation must be based on broad-beam data, otherwise they may be inadequate.

For *x* rays excited at voltages above 2 MV, there are no experimental values on broad-beam transmissions through lead. There are, however, data for concrete (Evans and others, 1952 ; Singer, Braestrup, and Wyckoff, 1946 ; Kirn and Kennedy, 1954).

* (Private communication). Curve deduced by Mr. E. E. Smith, National Physical Laboratory, from experimental observations of Evans, Granke, Wright and Trump.

TABLE 2

DOSE BUILD-UP FACTORS FOR *X* RAYS TRANSMITTED THROUGH LEAD

Thickness of Lead (cm.)	Dose Build-up Factors	
	1000 kV *X* Rays	2000 kV *X* Rays
0	1·0	1·0
2	1·4	1·5
4	2·1	2·2
6	3·0	2·5
8	4·0	2·8
10	5·5	2·8
12	6·9	2·9
14	8·5	2·9
16	—	3·0
18	—	3·0
20	—	3·0

Having estimated, by means of relationship (2) on p. 154, the maximum allowable percentage transmission through a protective shield to reduce the dose-rate of direct *x* rays to below 0·3 r per week, the thicknesses of lead which will transmit to this extent at known distances from *x*-ray sources of different energy can be read off from the given figures. In many cases, the designer of a radiological department will wish to translate the lead thicknesses into equivalent thicknesses of brick, concrete, or barium concrete (or plaster). Figures which will assist the translation, and which are based upon experimental work and new theoretical calculations. The growth of these factors with increasing thickness of absorber (expressed in terms of weight per unit area) in the path of the beam is illustrated in Fig. 3. These curves indicate that, for thicknesses up to about 70 lb./sq. ft., the transmission of broad beams of radium gamma rays is much the same for all materials. That is to say, the "density law", which is applicable for all thicknesses of materials for narrow-beam conditions, applies here also over a very limited range. Above 70 lb./sq. ft., the scattering conditions depend on the atomic number of the absorber; the heavier the element, the smaller is the scattering.

TABLE 3

RELATION BETWEEN THICKNESS OF BRICK AND LEAD EQUIVALENT AT VARIOUS *X*-RAY QUALITIES (BROAD-BEAM CONDITIONS)

Thickness of Brick* (in inches)	Lead Equivalent (in mm.) for *X* rays Excited at Following Kilovoltages							
	50	75	100	150	200	250	300	400
4·5	0·7	0·9	1·0	0·9	0·9	1·2	1·3	1·5
9	1·6	2·0	2·4	2·0	2·0	2·8	3·7	5·6
13·5	—	3·2	3·7	3·1	3·1	4·9	6·8	10·3
18	—	—	—	4·3	4·3	7·2	10	15·2

*Brick is yellow stock of density 1·6 g./cc.

TABLE 4

RELATION BETWEEN THICKNESS OF ORDINARY CONCRETE AND LEAD EQUIVALENT AT VARIOUS *X*-RAY QUALITIES (BROAD-BEAM CONDITIONS)

Thickness of Concrete* (in inches)	Lead Equivalent (in mm.) for *X* rays Excited at Following Kilovoltages										
	50	75	100	150	200	250	300	400	500	1000	2000
2	0·4	0·5	0·6	0·5	0·5	0·6	0·8	1·1	1·6	4·0	6
4	0·9	1·2	1·4	1·2	1·2	1·7	2·2	3·0	3·9	8·6	13
6	1·4	2·0	2·4	1·9	2·1	3·0	3·8	5·4	7·1	14	22
8	2·0	2·8	3·4	2·7	2·9	4·4	5·8	8·5	11	21	31
10	2·5	3·6	4·4	3·4	3·8	5·8	7·9	11	15	29	40
12	3·1	4·3	5·4	4·2	4·7	7·3	10	14	19	37	49
14	—	—	—	5·1	5·6	8·6	12	18	24	45	58
16	—	—	—	—	—	—	—	21	28	54	67
18	—	—	—	—	—	—	—	24	33	62	76
20	—	—	—	—	—	—	—	—	37	71	85
24	—	—	—	—	—	—	—	—	46	88	103
30	—	—	—	—	—	—	—	—	60	112	130
36	—	—	—	—	—	—	—	—	—	138	159

*Density 2·2 g./cc.

available information, are presented in Tables 3, 4, and 5.

Gamma Rays.—Information concerning the absorption of the gamma rays of radium, cobalt 60, caesium 137, and iridium 192 in lead and other materials is gradually accumulating.

As regards the absorption of radium gamma rays in lead, the data are summarized in a previous paper by the author (Binks, 1954).

Dose build-up factors have been deduced from these data. Similar dose build-up factors have been deduced for steel and brick from the author's earlier

TABLE 5

RELATION BETWEEN THICKNESS OF BARIUM CONCRETE OR PLASTER AND LEAD EQUIVALENT AT VARIOUS *X*-RAY QUALITIES (BROAD-BEAM CONDITIONS)

Thickness of Barium Concrete or Plaster* (in inches)	Lead Equivalent (in mm.) for *X* rays Excited at Following Kilovoltages							
	50	75	100	150	200	250	300	400
0·5	1·2	1·8	2·2	1·2	0·9	0·8	0·8	0·9
1	2·3	3·3	4·1	2·3	1·8	1·7	1·9	2·1
2	—	—	—	4·3	3·4	3·7	4·0	4·5
3	—	—	—	5·9	5·1	5·8	6·3	7·0
4	—	—	—	—	6·9	7·9	8·6	9·6

*Density 3·2 g./cc.

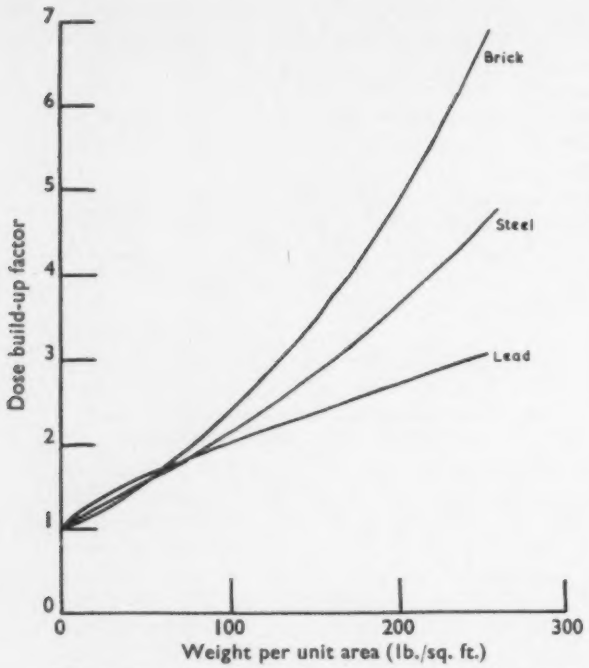

FIG. 3.—Dose build-up factors for radium gamma rays in lead, steel and brick.

Further data on the transmission through lead, steel, and concrete of broad beams of gamma rays from radium, cobalt 60, and caesium 137 are given in Handbook 54 issued by the National Bureau of Standards in September, 1954. On the basis of the above can be deduced the thicknesses of protective shields of various materials required, at known distances from different gamma-ray sources, to reduce the dose-rate for direct radiation below 0·3 r/week.

Oblique Transmission of High-energy Radiation through Walls

Considerable errors may arise from assuming, as has been done in the past, that the transmission of a high-energy beam of *x* rays or gamma rays obliquely through a shield is the same as for a beam passing normally through a shield of thickness equal to the slant distance in the oblique case. Measurements have been made (Kirn, Kennedy, and Wyckoff, 1954) of the oblique transmission, through lead and concrete, of the gamma rays from cobalt 60, caesium 137, and gold 198. The study reveals, particularly in the case of concrete, that the radiation transmitted along an oblique path is greater than that for normal incidence.

Scattered Radiation

Hitherto our efforts have been directed mainly towards the consideration of protective measures against direct beams of *x* rays and gamma rays. Scattered radiation has entered into these considerations, but only in so far as it is mixed with the direct beam. It is now proposed to deal, in more detail, with scattered radiation only and with the measures which are desirable to afford protection against it. Most of the measurements which have been made in the past have been concerned with the scattering in various directions from a patient, or " phantom " of wax or wood, of *x* rays excited at voltages between 50 and 200 kV. The results obtained have differed considerably. This would seem to be due to the fact that, if the beam falling on a patient passes very close to the side of the patient nearest the detector, much of the scattered radiation escapes from the body without re-absorption. On the other hand, if there is an appreciable distance between the edge of the beam and the edge of the patient, the softer scattered radiation may be partially, if not wholly, absorbed before it can get out of the patient. Such a spread of results (Binks, 1943 ; Wyckoff and Taylor, 1952) is portrayed in part of Fig. 4 in which the values of the percentage scattering (s) per 100 sq. cm. of field at 1 metre to the side of the scattering body are plotted against the *x*-ray energy. In this sense, " side-scattering " is taken to mean the scattering in a direction approximately at right angles to the direction of the primary beam. " Back-scattering " means the scattering in a direction opposite to that of the primary beam. The point plotted at 300 kV for concrete was obtained by the author ; that at 1000 kV is by Braestrup and Wyckoff (1948), that at 2000 kV has been deduced from observations

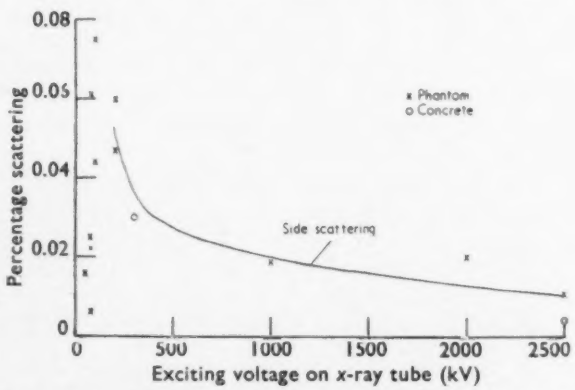

FIG. 4.—Percentage scattering per 100 sq. cm. of field at 1 metre from scattering body.

reported by Wilson and Perry (1952), whilst those at 2500 kV have been derived by the author from measurements by Dixon, Garrett, and Morrison (1952) with cobalt 60 gamma rays by expressing the energy in terms of the equivalent continuous *x*-ray spectrum. If the spread of results at 50 to 100 kV is ignored, and the maximum scattering which is likely to occur is taken into account, it would seem that the degree of side-scattering decreases with increasing energy of the primary radiation. This would be in accord with theoretical predictions.

In the few observations which have been made, back-scattering seems to be about three times greater than side-scattering; also, scattering from steel is three times less than from concrete. It is hoped that this information will enable reasonably safe estimates to be made of the maximum allowable percentage transmissions of shields intended to provide protection against scattered radiation (relationship (4)). At the same time it must be stressed that much more work is necessary in this field in order to unravel a complex state of affairs. In the low-voltage range (70 to 160 kV) Lindell (1954) has studied the energy spectrum of the 45° scattering from such materials as lead, tin, zinc, copper, aluminium, and paraffin wax, and has shown how the scattered radiation depends upon the energy of the primary *x*-ray beam and upon the atomic number of the scatterer. On theoretical grounds, he has calculated the shape of the curve to be expected when the total intensity of scattered radiation from different elements is plotted against the atomic number. There is a rapid fall from light elements to iron and copper, after which there is a rise up to tin and a subsequent fall to lead. From iron up to the heaviest elements, the scatter consists largely of characteristic *x* rays. Such characteristic radiation will have increasingly less importance at higher energies, for the protective shields required under these conditions will be able to absorb the characteristic rays much more easily than the Compton scatter.

Experimental data on the quality of cobalt 60 gamma-radiation, scattered at various angles from concrete, are provided in a paper by Dixon and his colleagues (1952). The scatter decreases in hardness as the angle between the direction of scatter and the primary beam increases. As regards absorption of the scattered radiation in concrete shields, roughly, the thickness required for 45° scatter is two-thirds, and for 90° scatter one-half, of the thickness required for the primary radiation.

X-Ray Crystallographic Units

The radiation hazards associated with the use of *x*-ray crystallographic equipment stem from the fact that (1) the inherent filter in the *x*-ray tube "window" is so thin that it transmits a much higher fraction of the rays, particularly of the soft components, than a tube designed for radiography, or therapy and (2) the distance between the tube and specimen is very short. The dose-rate in the beam is thus exceedingly high and may be of the order of 10,000 r/min. or more. In addition the soft radiation is easily absorbed in the superficial layers of the skin. Serious, and sometimes permanent, damage to the skin can therefore result from even a few seconds' exposure in the direct beam. Accordingly, the equipment should be so designed that adjustments of specimens cannot be made without an automatic beam shutter coming into operation. A protective screen should also be provided which will absorb the intense direct beam behind the specimen in the camera.

Measures have also to be taken to deal with scattered radiation which usually originates at the front face of the camera where this is irradiated by the direct beam en route to the crystal. Most of this scatter can be intercepted by passing the primary beam along the axis of a cylindrical lead sheath placed between the window of the *x*-ray tube and the face of the camera. Scatter which escapes through this system or which originates from other parts of the equipment can be dealt with by erecting a lead screen near the unit, after all adjustments have been made. Because of the comparatively low voltages used to excite the *x*-ray beams for crystallography, sheet lead, 1 or 2 mm. thick, proves quite effective as a shield.

Other Possible Sources of *X* Rays

Various types of apparatus not normally thought of as generators of *x* rays are at times potentially hazardous in this respect. Amongst these may be mentioned transmitting valves, rectifying valves, cathode-ray tubes, and television sets, when these are operated at voltages in excess of about 5 kV.

The intensity of the radiation emitted depends, as with any orthodox *x*-ray tube, upon the exciting voltage, the tube current, and the thickness of the tube wall. The results of measurements made with low-voltage *x* rays are given in Table 6. These refer to doses per 40 hours at 1 foot distance from a tube, with a tube current of 250 μA, which is of the order of the currents used in cathode-ray tubes in television sets.

It will be seen that if a constructional or maintenance engineer has to carry out tests with cathode-ray tubes in T.V. sets for any lengthy period he could under certain conditions receive dangerous doses. For example, a tube operating at 25 kV and having a glass wall 5 mm. thick could give the weekly permissible dose of 0·3 r in about 15 minutes at 1 foot. If for test purposes, the tube current is reduced to, say, 50 μA, the m.p.d. would still be received in a little more than one hour. The radiation, even at 25 kV, is, however, very easily absorbed, and is reduced by a factor of about 10,000 by 0·1 mm. lead or about 0·5 mm. steel. Shielding of equipment of this nature is, therefore, a simple matter.

TABLE 6
RESULTS OF MEASUREMENTS WITH LOW-VOLTAGE *X* RAYS

Operating Voltage (kV)	Thickness of Tube Wall (mm. glass)	Dose in r/40 Hours at 1 Ft.
6	0·5	0·0008
7		0·015
8		0·3
7	1	0·0003
8		0·003
9		0·03
10		0·3
10	2	0·003
12		0·08
14		2·5
14	5	0·0015
16		0·03
18		0·3
20		2·5
25		50
20	10	0·004
25		1

Radiation Surveys and Personnel Tests

It is important that a radiation survey should be made of any new or modified radiological department to test the structural shielding. Routine operation of such a department should be deferred until it has been found to comply with the basic principles of radiation hygiene. This, however, in itself is not a sufficient guarantee of safety of the staff, since in many instances such safety depends as much upon adherence to particular techniques as upon the provision of structural shielding. For this reason it is necessary to check the actual doses of radiation which the radiological workers receive by means of suitable photographic films or ionization chambers which are carried on the body during the course of duty. These personnel tests may be continuous or periodic, depending upon the circumstances. Continuous monitoring may not be necessary if the officer-in-charge is satisfied that, in the light of the initial radiation survey and of occasional personnel tests, the radiation level can never exceed the permissible amount.

The photographic-film test provides the simplest, and, perhaps, least costly, means of checking personnel doses. The evaluation of the dose received by a film is based upon the degree of blackening produced by the radiation. Unfortunately, the blackening depends on the quality of the radiation as well as upon the quantity. If, therefore, as is usually the case, the radiation is of mixed quality, the method of assessing the dose must be such as to err on the side of over-estimating. The main claim of the method is that it affords a simple way of revealing cases of over-exposure or of borderline exposure. When such cases are found, an inspection of the department concerned should be made by means of ionization chambers whose response to radiation is independent, or nearly so, of the quality.

The Radiological Protection Service

The author is the Director of a comparatively new organization—the Radiological Protection Service—which has been set up jointly by the Ministry of Health and the Medical Research Council.

The functions of the organization are: (1) to assist the appropriate committees in this country responsible for the evaluation of maximum permissible levels and for the preparation of codes of practice for the safety of radiation workers; (2) to give advice on plans of new and modified radiological departments and to carry out radiation surveys; (3) to provide personnel-monitoring services for both external and internal radiation; and (4) to carry out such research work as is necessary to supplement the efforts of other teams, both here and abroad, in acquiring the necessary information on which the satisfactory execution of the preceding three functions depends.

Conclusion

This survey will have served to show the present state of our knowledge regarding protection against *x* rays and gamma rays, and to draw attention to the gaps in that knowledge. More research work is needed to improve our understanding of the effects of radiation on man and of the processes, particularly for high-energy radiation, of absorption and scattering, so that radiation protection measures may lead to " function with economy ".

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Discussion

Mr. G. M. MICHIE (British Steel Castings Research Association) said that in many branches of industry today, mainly as a result of the availability of cheap radioactive isotopes, the extended application of radiographic inspection, notably of heavy steel castings, had taken place more quickly than suitably trained personnel had become available. In consequence managements had frequently to look for guidance in matters concerning both plant and protection to organizations outside their own companies, and to seek authoritative recommendations in connexion with proposed radiographic installations. As was well known, the Factory Department had given much guidance to many such companies, and had issued last year a useful pamphlet.

On the other hand, there was little doubt that what many firms required at the present time was something more concrete in the way of recommendations covering the precautions which they should observe if their personnel were to be adequately safeguarded, and an authoritative code of safe practice was a long-felt want.

The problem of providing adequate protection for personnel responsible for carrying out radiographic work with high intensity gamma-ray sources was undoubtedly the most difficult, since it was usually impracticable to adopt methods which would ensure that such personnel would never receive more than a dose-rate which, if maintained over the working week, would fall below the maximum permissible weekly dose. Thus, if the aim were to prevent operators from receiving at any time radiation intensities in excess of 7·5 milliröntgens per hour, isotope-handling rods would become unwieldy in length and containers so heavy that their positioning in awkward sites would prove a herculean task. A compromise must therefore be sought in which operators might receive higher dose-rates for short periods, to be compensated for in periods during which they were exposed to negligibly low intensity levels. In such circumstances it would be appreciated that the use of pocket ionization dose meters provided an invaluable safeguard, since they afforded a convenient method of keeping a continuous check on the radiation exposure received.

Mr. D. G. ARNOTT (The London Hospital) suggested that the time was ripe for some legislation regarding the use of the materials in question which would lay down minimum standards of safety. Such legislation could be enacted under the Radioactive Substances Act. There was a great deal of difference between what was done under the auspices of the Atomic Energy Association and what was done in laboratories outside. In the first case there was an organization in which everybody was concerned with radiological hazards, but in an isotope laboratory these interests had to be shared with many non-ionizing interests, and it was difficult to enforce standards of protection in those circumstances. Those who worked with isotopes knew of many instances where abuses had crept in, and he would not be surprised to find that the radioactive effluent discharged from Harwell in a year was less radioactive than that discharged from some hospitals—not his own—in a week. Such abuses were difficult, once established, to get rid of, because it was never easy to get rid of a precedent, good or bad, once it had been established.

Mr. W. BINKS supported Mr. Arnott's view. He would not necessarily maintain that it should be in the form of statutory regulations, because regulations normally had to be framed in such a way as to say that this must be done and that must not be done, and it was undesirable to hamstring the work which was going on by too detailed a specification. It appeared better to give guidance to workers through codes of practice. The first one was now nearly ready, dealing with the use of x rays and radioisotopes in hospitals.

Mr. MICHIE showed diagrams illustrating methods of calculating safe working distances and a plan for a safe exposure area. These are shown overleaf by courtesy of the British Steel Castings Research Association.

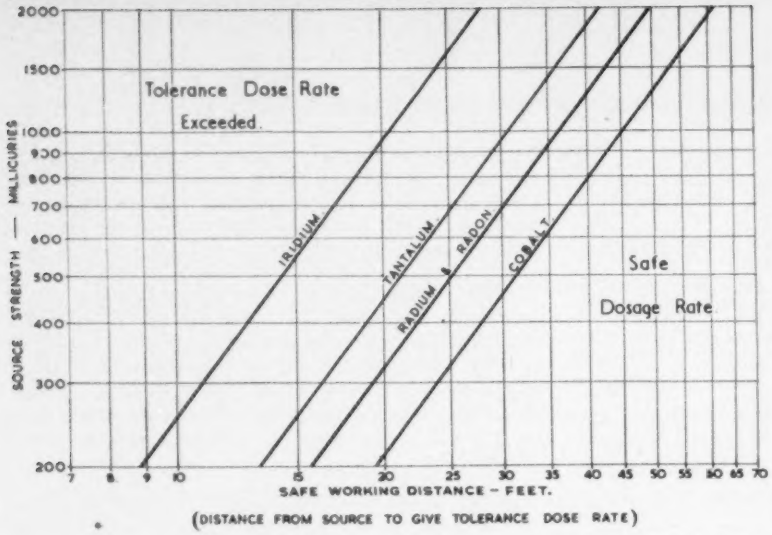

FIG. A

FIG. A.—This is a chart for indicating the distances from various unshielded radioactive isotopes at which the dose-rate is equal to 7·5 milliröntgens per hour, *i.e.*, the rate which, if continuously received over a 40-hour week, would eventually build up to the maximum permissible dose (0·3 röntgen). In the case of site radiography in factories, where the erection of permanent radiation shields was impracticable, this chart was therefore considered appropriate as a basis for determination of the distances from gamma-ray exposures at which some form of temporary barrier should be erected to prevent closer approach by unauthorized personnel.

FIG. B.—This is a similar chart for determining the thickness of brickwork shields (in this case for brick of density = 1·9 g./cc.), suggested as appropriate for surrounding radiographic exposures using ^{60}cobalt, in cases where construction of a permanent exposure site was being considered.

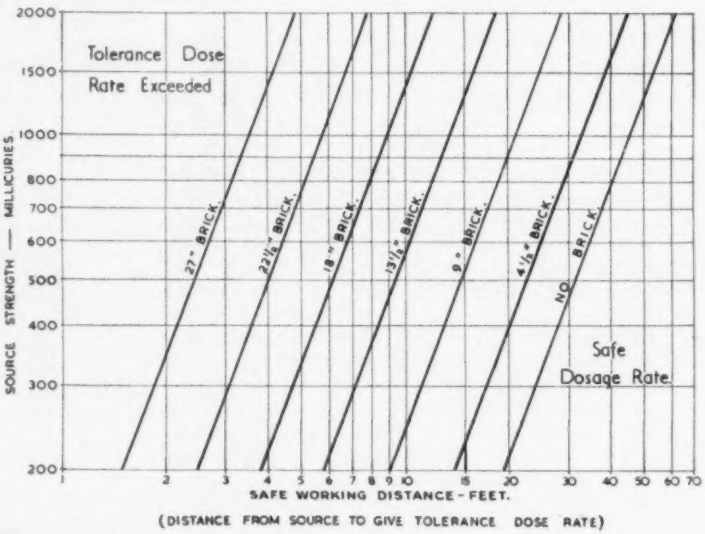

FIG. B

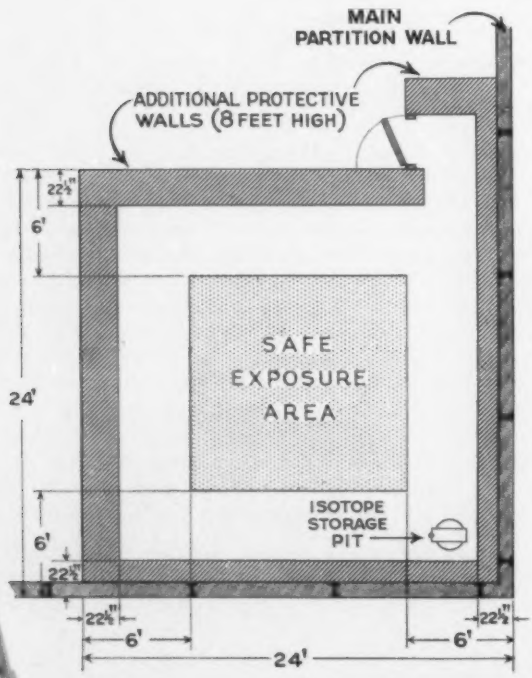

FIG. C

FIG. C.—This plan shows an exposure site of a type common in many steel foundries, the wall thickness being based upon the data given in Fig. B. Using a 1,000 mC source of ^{60}cobalt, it would be seen that, provided exposure of the source was restricted to locations falling within the area marked out on the floor, the maximum permissible dose rate would never be exceeded at the outside surface of the brick wall. The enclosure would normally be open at the top to permit heavy castings being lifted in and out by overhead crane. The height of the roof of the shop would ensure that back-scatter from this source did not present a problem.

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SAFETY CRITERIA IN ATOMIC ENERGY

BY

F. R. FARMER

From the United Kingdom Atomic Energy Authority, Industrial Group Headquarters, Risley

The Problem

The previous conference of this society dealt with the concept of tolerance levels in industrial activities. Today's conference has shown the importance of this concept in a new industry—that of atomic energy. The industry has an unfortunate history arising from its war-like introduction at Nagasaki and Hiroshima, and this has led to a considerable amount of confused thinking. Whenever atomic energy is mentioned, fear of an atomic explosion and the fear of death from a new cause are probably uppermost in men's minds.

The thesis I wish to put forward is not related solely to atomic energy, but deals with the more general problems of an approach to safety standards or tolerance levels. This subject is essentially one which is linked closely to the emotions rather than to the intellect, and it would be unfortunate if the association with atomic energy aroused emotion to such an extent that we could no longer think logically of the problems.

It has been stated that we should not be satisfied with our present achievement of safety in industry, nor should we be satisfied to remain just within tolerance levels laid down, but we should strive to reduce the hazard to zero. If this is the declared policy of the B.O.H.S., and is promulgated without qualification, what terms of reference do you give to those responsible for safety in a new industry? Is the policy to be followed regardless of cost? Can the nation pay any price to ensure a marginal reduction of hazard?

These are some of the questions raised by the proposition that industry should never be satisfied with an achievement in safety at any level, and must be answered if industry is rightly regarded as only one part of national activity.

The Varied Incidence of Accidents in Industry

Hazards in industry are extremely varied; for convenience in analysis they can be divided into a large number of categories, some giving rise to disease or ill-health in varying degree, others to accident or death. Some are easier to control or more easily anticipated than others, but fundamentally the sum total represents the hazard appropriate to a particular industry.

The reduction of the hazard may be brought about by the design of better equipment, by the adoption of new processes, or by better management exercised through staff selection, control, job planning. If unlimited resources are available any one of the hazards, and consequently the total, can be reduced.

I would expect to find that all industry had about the same accident rate, or that in industries showing higher than average figures the investment towards its reduction would be greater than the average. I find, in fact, a wide range of accident figures, and the difficulty in comparison arises from the definition of "accident". If this is based on time lost, other sociological factors would be introduced, such as the earnings in the industry, its past history, facilities immediately available, the goodwill of the industry.

A measure of hazard which has a more precise meaning may be taken from the number of accidental deaths, and these cover a range of 30 : 1 as between the highest and lowest given in the industrial classification for 1950. For every 100,000 employed in any one industry, the safe occupations showed a death rate of about 3 per annum, whereas mines and quarries showed a rate of 80 per annum. A large number of our industries have a rate of 8 to 12 per annum, that is 1 in 10,000. I am amazed at this diversity of risk, this inequality between the good and the bad, and in the light of the industrial safety policy declared earlier, I should expect to see an enormous effort applied to the reduction of risk in occupations showing the highest incidence.

Reduction of Industrial Hazards

Many attempts have been made to assess the cost of accidents in industry. I have not found a similar consistent attempt to determine the investment necessary to reduce the hazards. After a careful study of this question I have come to the conclusion

that it is impossible, in general, to derive any realistic measure of the applied effort towards safety. We are not given a nicely tailored example of two similar industries side by side, or of one industry before and after investment in safety measures. Neither can the cost of accident prevention be measured by the mechanical guards erected, or by filters or scrubbers inserted in a gas stream. The total effort is the sum of these plus other factors of greater importance, but inseparable from the all-over effort towards industrial efficiency, which includes design, layout, and management, each of which can only include safety as one aspect.

In the absence of a precise yardstick which would enable me to say that this industry invests £x toward accident prevention whereas that industry invests £y, I can only make a generalized approach. Does it use only the equipment known to be of the highest quality giving safest operating conditions? Are the best techniques of management applied? Are the operators selected more rigorously and better trained than those in other industries?

I do not think that these conditions are met with in our dangerous industries, but are in fact found in the efficient and successful industries which are operating with average or lower than average risk of accident. On the evidence available I believe that I am justified in coming to the conclusion that the effort applied towards the total elimination of accidents is not determined by good intentions, neither is it regulated by the current risk within an industry, but is, in fact, one aspect of wider economic considerations. Safety is only one aspect within the economic field and I am sure that few industries can afford to operate in any way other than the most economical. In spite of its numerous assurances to the contrary, industry does not do all that can be done to eliminate risk of accident, for this would cost too much. In order to survive, first as a nation, and secondly as an industry, we are forced to operate at minimum cost. This may be modified under certain conditions as a national policy.

It Pays to be Safe

The dictum of every safety officer, and the theme in all safety journals I have read is, " It pays to be safe ". This implies that steps taken towards safety operate towards greater economy and, in fact, in choosing to produce the cheapest article, industry chooses the route of safety. This can only be true up to a point, but in retrospect it is clear that the big strides towards reducing accidents in industry in the last 20 years have been made in the course of reorganization. In a growing industrial community each change has led to greater economy, and in many cases the change, of process or plant or of production method, is forced by competition.

In assessing maximum economy, accidents and deaths arising from industrial activity will all contribute towards the cost of production. Much has already been said and written on this subject, and it is often inferred that industry could not pay the bill for lost time and compensation arising from accidents, and for this reason is forced to improved and safer production. I cannot believe that this is in fact the position: it is inconsistent with the widely diverging death rate in our industries. Can one industry afford to operate at 80 deaths per year per 100,000 employees while another operates at 10 per year? The urge to reduce the lower figure of 10 to 9 or 8 cannot be based on directly incurred charges; the industry having 80 deaths per year would be forced to spend a large percentage of its income on preventive measures. It is more consistent to deduce that accidents play a minor role in production costs and that a continued reduction of risk is a secondary effect in industrial reorganization.

If in one industry the accident rate is very high, it is possible that labour will be loath to move into that industry and will demand higher wages, danger money, etc. The principle of danger money is already established, but this is more closely related to the job or to the severity of the risk rather than to the industrial economy and the probability of risk. There is comparatively little sign of reluctance to enter a hazardous industry, such as explosives; nor is there a particular consciousness of danger within such industries except possibly in the most hazardous—mines and quarries. Other aspects of the job outweigh the danger, and very few of us consider the risks we run in industrial and non-industrial activities and most people assert that their job is safer than investigators would have them believe.

Is There a Balance between Industrial and Non-industrial Hazards?

In considering the motivation for accident reduction, I have looked for modifications of the doctrine of maximum economy. It could be argued that this doctrine in its simplest form is the impersonal operation of the employer. If the employee were particularly conscious of risk he would modify the simple approach by seeking to impose restrictions in recruitment or by wage demands. In a highly organized state the employee also exercises control through his elected government by the imposition of regulation and inspection. I would expect both of these employee-directed impulses to be related to the health and well-being of the community. For

instance, in war time greater risks are tolerated, and, in an unhealthy community, the particular health hazards of industry do not excite comment. I would not expect an employee to be conscious of a risk which is small compared with the risks he already accepts in life, nor would he demand a standard of perfection from 7 a.m. to 5 p.m. which is vastly different from that prevailing outside these hours. This argument appears reasonable if we are comparing similar phenomena, if the results are the same, and if they are similarly understood.

The greatest risk we run is that of dying from natural causes. We are used to this idea, although there is an increasing reluctance to accept it as inevitable and we like to postpone it for as long as we can. We, as a nation, are prepared to invest a considerable sum in an attempt to delay death and to remove the unpleasantness and inconvenience of ill-health, which itself carries a probability of death, and certainly makes us conscious of death around the corner.

Twenty years ago of every 1,000 live births 220 died before the age of 45; today this number is 110, or, 110 people per 1,000 born reach the age of 45 who would formerly have died. Until we reach the age of 45 or over we are not very worried by the diseases of old age. Both as individuals and collectively as a nation we are concerned about death in the young and middle-aged and for every 100,000 people in this category today the death rate is 150 per year. This is made up of deaths from a variety of causes —influenza, pneumonia, tuberculosis, malignant diseases, and also the special category of death from violence. This category includes road deaths, deaths from falls, burns, drowning, suicide, and contributes to the total about 30 to 40 per 100,000. In other words, a worker is four times more likely to meet a violent death outside his working hours than within them. No single cause is outstanding other than violence which itself is subdivided, and our national investment is spread over, partly towards prevention, partly towards reduction in severity. If we wished we could concentrate our effort towards a narrow front or increase our effort in one direction. In recent years we have increased our expenditure on the National Health Service, and we have already reached the position where some say that we have reached or exceeded our ability to pay for these services. Others wish to increase the Service hoping to achieve better health through more frequent medical attention or improved hospital facilities. We all know that deaths occur today which could be prevented if we were prepared to invest a greater sum in safety. Apparently we do not choose to do this and we are only prepared to insure ourselves against these natural hazards at a premium of £10 per head per annum.

The Community Outlook on Hazards

Against this background, in which we see that a young population of 100,000 can expect 150 deaths per year, the hazards of industry can be seen in perspective. An additionally imposed rate of fewer than 10 per annum represents a 7% increase, and there is no reason to expect that this 7% will respond to treatment with greater ease or lower expenditure than any other cause making up the total. On the other hand, a rate of over 70 per annum per 100,000 employed represents an increased risk of death of 50%.

I suggest that in relation to known and existing hazards the community unconsciously makes a comparison, and we should expect that as the greater risk of death from natural causes is reduced then there would arise a growing dissatisfaction with any additional hazard which has not similarly decreased. The trend in industry has followed the trend in national health and I would expect both to improve without necessarily requiring greater effort. There remain today two outstanding causes for dissatisfaction, death from road accidents and from accidents in mines. These are in a similar category: both are the effects of violence; neither can remotely be called an "act of God" and accepted currently as an evil to be borne by the human race. In both cases the extent to which effort is applied towards a reduction is determined for the most part on an economic basis, modified only slightly by pressure of public opinion.

The frequency rate for road deaths is 12·5 per 100,000 of the male population and as such is comparable with the rate in many industries, but it is only one-sixth of the rate for mines.

The Introduction of New Hazards

Earlier, I mentioned the effect of emotion and I agree that individually and collectively we live as much by the emotions as by the intellect. I have no desire to belittle the value of emotion, but too often a muddled gushing of sentiment is offered in place of a reasoned policy.

I believe, however, that policy should first be decided in an unemotional atmosphere and that emotion should be used to implement this reasoned policy which will still take human values into account.

As a nation our policy is largely decided by £ s. d. and essentially all of our industrial activities are similarly determined. However, if a new hazard appears, this premise may no longer be applied.

When once an uncertainty or fear begins to spread a very much greater effort is demanded by the public. Fear is undoubtedly catching and may be set off by trivial things with or without substance. In our everyday life the fear of poliomyelitis is very marked and its effect on our national economy is far greater than its relative incidence compared with better known afflictions. In this case the fear may or may not be justified, but once initiated it is not easily dispelled. This point was made by the Chief Medical Officer in his report for 1950 :—

> " The outbreak [of poliomyelitis] in the Isle of Wight gave some measure of the public alarm ; it spoiled the holiday traffic and deprived thousands of their vacation in this lovely island. In spite of the special vigilance of the practitioners and the unusual readiness of the people to consult them during the five weeks of the outbreak, only 49 cases were notified, of which 41 were paralytic. These 49 cases were specially studied and most were found to be linked in a chain involving, with one or two exceptions, only permanent residents in the island. It is unlikely that the incidence among holiday makers was above the average for the whole of the country. Clearly the public alarm, kindled by spectacular journalism, was unnecessary and unrealistic.
>
> " The public anxiety also tends to be exaggerated because the outcome of the disease is not generally understood."

Similarly the advent of atomic energy is in the public mind associated with fear of the unknown and the horrific—with sterility, the loss of hair, with abnormalities in future generations.

Against this background and that of current industrial trends, what standards should we adopt in safeguarding the future development of this new industry ?

Application to the Early Development of Atomic Energy

You have already heard how tolerance levels have been laid down by international agreement and how these have been measured and enforced at Windscale. We are aware that most of the tolerance levels contain a considerable safety factor but in addition we choose to insert further safety factors in our application of these levels. In this way we allow for our lack of knowledge in the chain of events from plant operation to the point at which the tolerance level could apply ; that is, from plant operation to airborne hazard, or from effluent emission to human intake or from a gamma-ray source to the point of exposure. For the first time in the development of a major industry the following conditions exist : (1) Freedom from competition or any externally imposed monetary scale for its product, and (2) an initial awareness of the hazards involved in the industrial operations.

Under these conditions the apparently conflicting demands of economy, simplicity, and speed of development were heavily outweighed by the need for safety, and, at considerable cost, the industry has achieved a record which is outstanding by comparison with any major industry today. This is true not only in relation to the special hazards of radioactivity but also in relation to the commonly accepted form of accident arising from any industrial operation.

In the latter category of deaths entirely dissociated from radioactivity, our rate is one-third to one-quarter that in the engineering, chemicals, gas, and electricity undertakings, and yet these industries consider their own records something of an achievement. Our accident rate is also running at a far lower figure than the average in industry today.

The radioactive hazards are, as you know, divided into the two groups of internal and external radiation. In the former group, not one single case has occurred showing any symptoms whatsoever of temporary over-irradiation. Our yearly records of over 100,000 films show that no employee has exceeded the average maximum tolerance level and that over 96% have received an exposure of less than one-tenth of this level.

Most of the airborne tolerances are based on a life-time accumulation so that small hour-by-hour variations are of less importance than is the case with many industrial hazards giving rise to acute conditions. Even so, our intensive air-sampling campaign has shown that over 98% of samples lie at a level of less than the long-term tolerance.

Application to the Longer-term Development of Atomic Energy

The record quoted is one of which we are justifiably proud, but it has been achieved at considerable cost. We are already moving away from the initial phase and the nation is expecting to see big strides made in peace-time applications. If you accept the premise that atomic energy is an essential industry then it must go ahead in competition with other industries. The money invested is an alternative to investment in some other enterprise.

Concurrently with the urge to develop competitively, we have gained a considerable understanding of the hazard and its control. I believe that the tolerance levels accepted by international agreement are as realistic as most tolerance levels for industrial hazards. Our measuring instruments are, for the most part, capable of infinitely more sensitive determinations than those for the chemical poisons even in relation to the limits laid down. This enables us to operate with greater confidence, and with a high

degree of certainty that our operations can be conducted within the tolerance levels. I am of the opinion that our probability of exceeding the danger level is far less than 1 in 100,000 per annum, that is less than one-tenth of the current industrial death rate, or less than one-fortieth of the probability of death by violence.

If the tolerance levels move up or down, our design and operations can follow—at a cost or with commensurate saving. If this new industry is to progress competitively it is essential to ensure that realistic levels are agreed and always maintained as such, following the growth of knowledge and operating experience. This does not relieve the industry of its obligation to work to the highest possible safety standard within any given economic framework and that we should always pursue the goal of zero risk with the expectation that greater safety and greater economy will advance together through the exercise of the best engineering and management practices available.

Discussion

Dr. J. F. LOUTIT (Radiobiological Research Unit, Harwell), in opening the discussion, said that the records of the atomic energy industry today were beyond reproach, but it had never been expected that there would be troubles in the first few years. The International Commission on Radiological Protection and its British national counterpart, which were responsible for setting permissible levels, had in their calculations to envisage that in the industry in the future employees would go on in routine jobs involving exposure to radiation for 25, 35, and perhaps 40 years. It was essential for this reason to have these safety factors. Furthermore, there was very little experience of the hazards from plutonium and fission products, and it was possible to estimate only on the basis of experience with other radioactive materials such as radium. Thus there might be some doubling up of safety factors with regard to the internal hazards.

The safety factors against the hazards from external radiation were in his view very slim indeed. In spite of their 50 or 60 years of experience with external radiation they had no truly scientific data at all about its hazards to man. They had records, it was true, of the *x*-ray martyrs and knew that people had died of bone diseases and of blood diseases, but they did not know the doses which those people had received. It was only possible to hazard guesses, and to relate those guesses to the observed clinical results.

It was their best guess that 0·3 röntgen per week in tissue would not cause damage when spread over a 30-year or 40-year working life (0·3 röntgen per week was approximately 7·5 milliröntgens per hour). What happened if the dose-rate of 7·5 milliröntgens per hour was exceeded? Some thought that it was perfectly permissible provided one kept within the global dose of 0·3 röntgen per week, but not everybody took that view, notably the Swedes.

Blood counts had been somewhat discounted earlier in the Conference, and he personally was in agreement: but data from Sweden (Helde and Wahlberg, 1953) had been published on blood counts of men in different types of radiological work. They received varying doses from 1 to 100 or so milliröntgens per week above the local background and the abnormalities in their blood had been scored in terms of percentages. It was noted that some groups had 30% of abnormal leucocytes with relatively high doses within the permissible range. Others had the same percentage of blood changes with average doses 100 times lower. At first sight there seemed to be no sense in what was found, but when Helde and Wahlberg considered these groups in terms not of the global dose per week but of the dose-rate the anomaly disappeared and there was a beautiful correlation between percentage abnormalities and dose-rate. That was now generally accepted in Sweden.

At Harwell, Dr. Mole had attempted to survey the literature to assess the value of blood counts (Mole, 1954). Although many of the *x*-ray and radium martyrs died of aplastic anaemia, only very few records were available of prior blood counts. These showed that a few months before their deaths they had absolutely normal figures.

If a man was due to die of aplastic anaemia in a month or so, one might have expected some signs of warning. On the other hand the observation may not be so surprising, because one knew what happened in the case of other tissues, such as the liver. Function could be maintained by a grossly damaged liver, and it was only at the last moment that there were demonstrable chemical signs of liver failure. Similarly, it was possible that damaged bone marrow could keep the elements of the peripheral blood at normal levels until a point of exhaustion was reached.

There were, therefore, those two opposing views, the Swedish view and the one which he had just postulated. There was still room for operational research in these matters and not only from the conventional clinical point of view of blood counts. From the results of experimental animal work at Harwell he considered damage to the gonads as most important.

Mice had been chronically irradiated from about the age of 3 months until they died. The white cell count, which was regarded as the most sensitive index in the blood, remained perfectly normal, but it was seen that male fertility fell to zero within three months, and female fertility within five months. Thus male fertility and female fertility fell demonstrably long before there was any abnormality in the white cell count, and in fact there had been no abnormality in the white cell count, even at death. It was noted that testis weights paralleled closely male fertility.

He would like to ask industrial health officers whether it was possible in the twentieth century to make some objective investigation of fertility, apart from scoring births. Was it possible in this enlightened age to obtain some objective measure like blood counts, such as sperm counts, on industrial workers to see whether the safety

measures which were taken as regards external radiation were in fact as safe as one hoped that they were?

American workers in Rochester had shown that with dogs the same sort of thing occurred. With doses of one röntgen per day after two years the dogs were at least grossly infertile. He was not saying that the sexual behaviour of mice or dogs was comparable with that of man, but he thought that there ought to be more data on man than were available at the moment.

Dr. E. F. EDSON (Pest Control, Cambridge) thought that the main point for discussion was the problem of whether too much money was being spent on protection (*a*) in industry as a whole and (*b*) in the new atomic energy industry. That was a matter on which many people in industry must already have pondered. The question was very often asked, "Why do you spend so much money on protecting the worker when his chance of being killed on his way home on his motorcycle is already so much greater than the risk which he runs in the factory?"

It might be said that road accidents were a major source of risk to people today, as indeed they were, and might perhaps be an even greater source of risk to the next generation, and that not enough was being done about it. To say that was to see only one side of the picture, however, overlooking the work done by local authorities, voluntary organizations, the police, and, indeed, by taxpayers generally. The total amount of money and effort which was being spent on improving the roads and decreasing road casualties was already large. Similarly, a good deal was heard about the difficulty of controlling morbidity and mortality in mines, quarries, and other hazardous industries. The major competitors with atomic energy in the production of power were oil, which had to be brought to this country by sea, a somewhat hazardous occupation, and coal, production of which had one of the highest hazard figures in industry. If the present safety levels in atomic energy factories continued then atomic energy was probably the safest form of power as far as risks in production were concerned.

The public emotions and apprehensions were often blamed for large governmental expenditure on safety in atomic energy works. There was no point in negligently adding to the existing risks of life where there was an opportunity to control new hazards. In due course it would probably be possible to settle down to a lower cost per worker per annum for protection when it was possible to agree on the proper needs of the situation. We were probably providing some over-protection at present in the atomic energy industry. The lesson of the beryllium industry, however, must not be forgotten. The beryllium industry was carried on for many years without any significant casualties, but during the last 15 years it had been shown to have produced a large number of cases, many of which, the early ones, had almost been missed. Nowadays the protection of the worker in the beryllium industry costs almost as much as in the atomic energy industry. The trouble arose because the degree of changes and occupational hazards had not been detected in the early stages; he had said earlier that he felt the atomic energy authorities should not be too quick to blame themselves for spending too much money on radiation protection. Public opinion, which was important, would prefer them to spend a little more money in the first 10 or 25 years, rather than to have a large amount to pay in the next generation.

Mr. J. R. HODKINSON (Safety in Mines Research Establishment) said that one might conclude from Mr. Farmer's paper that, as fatalities in atomic energy work were so very much lower than in the safest of other industries, their figure might be allowed to rise from 0·1 per 100,000 to 1 or 2 per 100,000 in return for a saving in the present very large expenditure on protection. He thought, however, that the accident rate was not so simply related to safety expenditure; that there was no stable, half-way position in radiation protection; that a position of control was reached only when the hazards had been reduced to a very low level.

The PRESIDENT asked whether the workers in coal-mines had anything to say on the problem of whether too much money was being spent on protection.

Dr. J. M. ROGAN (National Coal Board) remarked that accident rates in the mines were extremely high, but they were about half the rate in German mines (the present death rate in British mines was about half what it had been 20 years ago) and only one-third the death rate in the American mines.

The coal-mining industry was now reaping the harvest of the conditions which had existed many years ago. There was a considerable amount of pneumoconiosis in the industry. The disease had developed insidiously as a result of dirty conditions underground once thought to be harmless. He would therefore advise the new Authority which was concerned with atomic energy that so long as they were doubtful about their permissible levels they ought to err on the side of safety. In coal-mining they found it difficult to attract men into the mines, although this was necessary for the country's survival. It might be that within the next 20 years the country's survival would also depend on atomic energy, and unless those concerned did all that they could within reason to protect their people now, they might be in a very difficult position in the future, especially if they found that the gonads had been affected.

Mr. M. JACOBSEN (Chemical Workers Union) said that atomic energy was a comparatively new industry in which, because it was new and because not enough was known about permissible levels, safety precautions had been instituted which might even be in excess of what was really necessary. That ought to be regarded as a boon to the community, because some of the older industries, like coal-mining, had not had the benefit of such an attitude and were now suffering from the results of that neglect, and had been doing so for the last hundred years. More money should be made available to reduce hazards elsewhere to the level which the atomic energy industry aimed at achieving.

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MISCELLANEA

Occupational Dermatitis Caused by Ethylene Oxide

A. ROYCE and W. K. S. MOORE

From the Microbiology Division, Standards Department, and the Industrial Health Unit, Boots Pure Drug Co. Ltd., Nottingham

Ethylene oxide exists as a colourless gas at ordinary temperatures, but at 10·7° C. it condenses to form a water-white liquid. It is miscible with water in all proportions and forms hydrates. It combines with compounds having a labile hydrogen atom such as water, alcohols, ammonia, and organic acids, although at ordinary temperatures some of these reactions are very slow. It will also abstract the elements of hydrochloric acid from aqueous solutions of chlorides forming ethylene chlorhydrin thereby yielding alkaline solutions.

Phillips (1949) and Phillips and Kaye (1949) have drawn attention to the sterilizing action of gaseous ethylene oxide in a series of papers, and Wilson and Bruno (1950) studied its application to the sterilization of bacteriological culture media and other biological fluids.

Physiologically ethylene oxide is an irritant, and causes severe inflammatory changes in the lungs, respiratory tract, and eyes of animals after exposure to the vapour. Severe damage has been found in the kidneys of experimental animals, showing that ethylene oxide or its products may act as systemic poisons after absorption through the lungs. The main effects so far observed in man concern the skin. Sexton and Henson (1949) have reported burns produced by dilute aqueous solutions of ethylene oxide when there was intimate contact with the skin and evaporation was impeded. On the other hand, pure liquid ethylene oxide may be poured on the skin and allowed to evaporate without producing anything more serious than a sensation of chilling.

The present report describes the circumstances in which several workers experienced rashes as a result of contact with gaseous ethylene oxide.

Description of Apparatus

A hermetically sealed screen was devised by one of us (A. R.) for performing aseptic operations. The device consists of a metal box provided with windows, a door, and two arm holes. Long rubber gauntlets terminating in rubber gloves are sealed at the arm holes (Fig. 1). When the screen has been loaded, ethylene oxide vapour is introduced and allowed to remain for 18 to 24 hours. After this period of sterilization, the vapour is flushed out by introducing a rapid air current into the screen through a filter, simultaneously extracting through another filter. After 30 minutes nearly all the ethylene oxide is removed, and the screen is ready for use. Aseptic operations can be conducted without risk of accidental bacterial contamination, and without any " scrubbing up " on the part of the operator, who simply

Fig. 1

Fig. 2

puts her hands into the gloves and proceeds with the work (Fig. 2).

Experience with Screens

The screens were first used early in 1951. During 1952 one woman, A, occasionally developed a slight rash on her fingers, hands, and lower arms, which was attributed either to the effects of sweating inside the rubber gloves or sensitivity to the rubber. At this time no rashes occurred among 10 other women engaged intermittently in the same work, and it was concluded that A had some personal idiosyncrasy and she was given other work.

No further trouble occurred until April, 1953, when another operator, B, developed a rash, and within a few weeks C, who replaced B, was similarly affected. At this time, work in the screens was increasing, and was beginning more quickly after flushing. It was not long before a further operator, D, was affected.

B's rash, which began in April, involved both forearms and wrists, and consisted of papules set on an erythematous base. C reported to the surgery in September, 1953, with a rash which appeared after she had been working in the screens daily for one week. The condition improved when she was given other work, but reappeared 12 hours after she had done another spell of one hour in a screen. The eruption consisted of erythema and oedema with numerous vesicles, involving the hands, wrists, and forearms only.

It had become obvious that the girls working in the screens were reacting either to contact with the rubber itself or to some chemical used inside the screens which was penetrating through the rubber of the gloves and gauntlets. Many substances are handled in the screens, some of which are known to cause skin reactions.

Experimental

A series of experiments was carried out to try to determine, if possible, the exact cause of the rashes. The patch test described by Schwartz (1948) was used in this investigation. The test materials were placed on the skin of the upper arm, previously cleaned with ether, and a piece of non-waterproof cellophane was placed over the test patch, then the whole was covered with a round piece of adhesive plaster.

(1) Operators B and C were patch tested with pieces of unused rubber cut from new gloves and gauntlets, and from those used in the screens on many occasions. No reactions developed.

(2) Operator D was patch tested by applying a small piece of gauntlet rubber which had been stored in a tightly closed screw-capped 50-ml. bottle containing 1 ml. of liquid ethylene oxide overnight. A ++ reaction developed in 24 hours (Table 1).

(3) After reading this reaction two male volunteers, E and F, had patch tests from the same sample of rubber used in (2). No reactions developed, but at the time of applying these patches there was no liquid ethylene oxide remaining in the bottle with the rubber. On opening the bottle, however, a distinct smell of ethylene oxide was noticed.

(4) Female volunteers G, H, I, and J, together with the operators already mentioned who had contracted rashes, were classified as follows :—

(*a*) Persons with a history of severe rashes (B and D); (*b*) persons with a history of slight or transient rashes (G and H); (*c*) persons without a history of rashes (F, I, and J).

Patch tests were applied using the following materials :

Sample 1.—New unused rubber (groups tested : *a*, *b*, and *c*).

Sample 2.—The rubber remaining from experiments 2 and 3 (groups tested : *a*, *b*, and *c*). (The smell of ethylene oxide in the bottle was very faint at the time of applying these tests.)

Sample 3.—New unused rubber which was freshly removed from a sealed bottle containing liquid ethylene oxide, in which it had been stored for 24 hours (groups tested : *b* and *c*).

Results

The results of these tests are shown in Table 1, from

TABLE 1

Group	Volunteer	Sample 1	Sample 2	Sample 3
a	B	−	−	··
	D	−	−	··
b	G	−	−	+++
	H	−	−	+++
c	F	−	−	+++
	I	−	−	++
	J	−	−	−

− = No reaction.
++ = Redness, oedema, and blisters.
+++ = Redness, oedema, blisters, and ulceration.

which it was evident that (1) none of the subjects reacted to patches from sample 2. Even D, who reacted so strongly to this material when it was freshly prepared, gave a negative reaction. (2) All subjects tested, except one, reacted to patches from sample 3; the single negative test was due to the failure of the adhesive plaster covering to stick properly on the skin. This uniform susceptibility of all volunteers shows that the skin reaction is due to direct irritation and not to allergic sensitization. (3) The skin reactions were not limited to the area of skin covered by the patch of material used in the test, but covered the whole area of skin sealed under the adhesive plaster. This showed that the vapour of ethylene oxide was responsible for these skin reactions. (4) Rubber soaked in ethylene oxide and allowed to stand for some time in air lost its capacity for causing irritation.

Ethylene Oxide in Rubber

It was evident that information was now required on the amount and rate of uptake of ethylene oxide by rubber and its subsequent rate of loss.

Ethylene oxide in rubber was determined by a method based on that of El Khishen (1950) using a saturated aqueous solution of magnesium chloride acidified with standard hydrochloric acid. Pieces of rubber treated with ethylene oxide were transferred to measured volumes

of this solution contained in stoppered flasks, which were shaken at intervals for three hours, the residual acid then being titrated with standard alkali using methyl red as indicator. Appropriate blanks were performed.

Rubber Saturated with Ethylene Oxide.—Pieces of rubber (weighing 1 g.) were cut from gauntlets and stored in liquid ethylene oxide in a sealed bottle overnight. They were removed the next morning, hung on hooks in air, and the ethylene oxide content measured at intervals (Table 2).

TABLE 2

Time of Exposure to Air after Removal from Ethylene Oxide	Ethylene Oxide Content (mg./g. Rubber)
1 min.	600.0
1 hr.	37·2
2 hrs.	6·8
3 ,, ...	3·3
4½ ,, ...	1·0
Control (untreated rubber) ..	NIL

Rubber Treated with 10% v/v Ethylene Oxide Vapour.—Further pieces of rubber were treated with 10% ethylene oxide vapour in air overnight, the proportion of rubber to ethylene oxide in the vessel being approximately the same as the proportion of rubber to ethylene oxide in daily use in the screens. Three experiments were carried out with brown gauntlet rubber, with the results shown in Table 3. The conditions of airing were varied from

TABLE 3

Time of Exposure to Air after Removal from Ethylene Oxide	Ethylene Oxide Content (mg. Ethylene Oxide/g. Rubber)			
	Brown Gauntlet Rubber			Red Glove Rubber
	Expt. 1	Expt. 2	Expt. 3	
1 min. ..	15·4	15·4	13·0	12·0
5 ,, ..	—	—	8·9	—
15 ,, ..	9·7	7·5	7·8	6·3
30 ,, ..	6·7	5·5	7·6	2·3
1 hr. ..	3·7	3·8	4·3	1·1
2 hrs. ..	1·9	1·5	2·0	0·5
4 ,, ..	0·4	0·6	0·6	—

undisturbed air (experiment 1) to vigorous draughts (experiment 3) and there was practically no difference under these various conditions. One experiment was carried out with the thinner, fabric-lined red rubber used in the screen gloves. This picked up somewhat less ethylene oxide, and lost it more quickly than the brown rubber.

Modifications of Working Methods

The normal method of using the screens was to clear them of ethylene oxide by flushing with air for 30 minutes, and then for work to start from a few minutes to one and a half hours later, depending on circumstances. The gloves and gauntlets were extended into the screen during the clearing process, and previously were left in this position until work began.

In view of the experimental results it was decided to clear the gas as before, but then to extend the whole of the glove and gauntlet outside the screen, and allow the rubber to air off for a further one and a half hours before work started (Fig. 1). This period would not involve undue delay and at the same time it would allow the concentration of ethylene oxide in the rubber to fall considerably.

To test the efficacy of this method operators B and D carried out work in the screens. B worked in a screen for one hour on two consecutive days and for two hours on each of two further days, while operator D worked for one hour on two consecutive days. No reactions occurred on these occasions, but both operators developed transient rashes at a later date.

As a further modification a length of thin rubber tubing was introduced into each gauntlet when the operator began work by tying loops to the ends of the rubber tube and fastening them round the operators' thumbs. A slow current of air was passed along these tubes while work proceeded, anticipating that the air current would remove small pockets of gas accumulating in the extremities of the gloves and gauntlets. Subsequently, operator B carried out work on six more occasions, and operator D on 12 more occasions without any trouble.

A and C, who had suffered rashes in the past, were then allowed to work in the screens, and although C had slight erythema on one occasion, they had no further rashes.

The experience described shows that rubber absorbs ethylene oxide to a marked extent, and that under the conditions described here the gas is capable of producing severe skin irritation. That the rashes experienced were due to direct irritation and not to any form of allergy seems clear from the fact that all volunteers reacted to the gas irrespective of their previous histories. Although the affected workers appeared to show differences in susceptibility, these differences are probably explained by postulating variations in the time allowed for airing the rubber, which would affect the ethylene oxide concentration significantly.

Sexton and Henson (1950), in describing their experiments designed to show the relationship between concentration of ethylene oxide and time of exposure, mention that three of their volunteer subjects developed hypersensitivity about three weeks after beginning the experiments. This hypersensitivity showed itself by a recrudescence of inflammation at sites of previous contact. No such phenomenon was seen among our cases.

Precautions designed to allow the rubber to lose the absorbed ethylene oxide by evaporation, and to prevent the formation of pockets of gas within the gloves and gauntlets, were completely successful.

The thanks of the authors are due to those members of the Microbiology Division who volunteered for the investigation.

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Blood Examinations in Industry : A Comparison of Blood Cell Counts from Ear Lobe and Thumb Pulp

A. BUTTERWORTH and N. GOODMAN

From the U.K. Atomic Energy Authority, Industrial Group, Springfields, Preston, and the Nuffield Department of Occupational Health, University of Manchester

Blood examinations are often included in the routine medical supervision of workers exposed to hazards such as lead, benzol, and the ionizing radiations. It is obviously desirable that the method of securing the sample should cause as little inconvenience as possible. Two sites are commonly used, the ear lobe and the thumb or finger pulp ; the latter has disadvantages because it involves puncture of a highly sensitive area through hard and thick skin. Furthermore, the hands are likely to need prolonged cleansing, especially among those in contact with radioactive material (Gregory, 1953). Many of the standards now accepted in industry have been based on the examination of blood obtained from the thumb or finger pulp, and before suggesting to industrial medical officers that it is both quicker and more convenient to take blood samples in industry from the ear lobe, it was thought wise to see whether values from the two sites differed. Previous work such as that of Humperdinck (1938) and Sørensen (1941) compared repeated samples from each site under experimental conditions ; the present work aimed specifically at comparing samples from the thumb pulp with that from the ear lobe when taken during routine working conditions.

Method

Every sixth person reporting for a routine blood count to the Medical Department of a United Kingdom Atomic Energy Authority's works was seen by one of two senior and experienced technicians. Samples of blood were taken from the ear lobe and thumb pulp. The first drop of blood was discarded. New B.S.S. pipettes were used and each was numbered for identification ; the equipment was carefully inspected daily for damage. Each technician carried through all the processes of counting for all samples he had collected. In order to eliminate any differential effect of diurnal variation found by Shaw (1927) and Chamberlain and Turner (1952) blood was taken only between 9.45 and 11.45 a.m.

One pipette of blood was used for the red cell count and one for haemoglobin estimation, for which the M.R.C. Grey wedge photometer was used. For the white cell count two pipettes of blood were taken as suggested by Chamberlain and Turner (1952) whose method of counting was followed. For the differential count at least 200 cells were examined. Seventeen male patients were seen by one technician and 18 by the other.

Results

Total White Cell Count.—The difference between the total leucocyte count for the two sites for each patient was examined. The average difference of 50 per c.mm., tested by Fisher's t test, was not significantly different from zero and thus there was no evidence that the site made any difference to the total leucocyte count ($t = 0{\cdot}34$; d.f. $= 34$; $0{\cdot}8 > P > 0{\cdot}7$).

Chamberlain and Turner found that the coefficient of variation of white cell counts varied from 10% when the mean count was 4,000 to 8% when the mean was 10,000. It can be assumed that, once in 20 pairs of repeat readings from the same site, experimental error alone might cause a difference of twice this magnitude from the mean. Here the counts from the two sites differed to such a degree in only two of the 35 cases, and so there was no evidence that the samples were of different blood.

Differential Count.—Similar tests were made for the differential counts and the average difference in readings from the two sites was not significantly different from zero for any of them.

	Mean Difference of Counts (per c.mm.)	t	d.f.	
Neutrophils ..	140	1·6	34	$P \sim 0{\cdot}1$
Lymphocytes..	94	1·2	34	$0{\cdot}3 > P > 0{\cdot}2$
Monocytes ..	11	0·55	34	$P \sim 0{\cdot}6$
Eosinophils ..	12	0·74	34	$0{\cdot}5 > P > 0{\cdot}4$
Basophils ..	1	0·18	34	$0{\cdot}9 > P > 0{\cdot}8$

Here, Chamberlain and Turner found that the coefficient of variation of the absolute count (*i.e.*, the product of two independent variables) ranged from 11·5% when the proportion of the individual white cell was a half of the total to 32% when the proportion was one-twentieth. The readings obtained from ear or thumb were again in accordance with this range.

Red Cell Count.—Berkson, Magath, and Hurn (1940) found the coefficient of variation of the R.B.C. count, using one pipette, one chamber, and counting 80 small squares, to be approximately 8% for a count of 5,000,000 R.B.C./c.mm. In the present study the magnitude of the readings from the two sites was consistent with this finding. When, however, the individual differences between the two sites are examined, the average difference of 157,600 per c.mm. is significant statistically from zero ($t = 2{\cdot}6$; d.f. $= 33$; $0{\cdot}02 > P > 0{\cdot}01$). Thus it appears that, although the counts for each patient from the two sites agree in magnitude within the limits of experimental error, there is a tendency for the ear counts to be slightly higher. In the 34* cases considered, the ear readings were higher in 26 and lower in eight cases, a bias which is unlikely to have arisen by chance ($\chi^2 = 9{\cdot}5$; $P < 0{\cdot}01$). Upon examination this difference was shown not to be due to any bias of technician or pipette.

* One of the 35 pairs of samples could not be used for red cell count or haemoglobin estimation.

Haemoglobin Estimation.—The average difference in the haemoglobin estimation (in g./100 ml.) for ears and thumbs was not significantly different from zero, hence there was no evidence that the site chosen made any real difference to the estimation (mean difference = 0·22 ; $t = 1·2$; d.f. = 33 ; $P \simeq 0·2$). The ear sample estimation was higher than that of the finger in 22 cases, equal in three, and lower in nine cases. Again, if it is assumed that there should be an equal chance of readings from one site being above or below those from the other site, the evidence is such that a bias is possible ($\chi^2 = 5·4$; $0·05 > P > 0·01$). This tendency would be consistent with the findings for the red blood cell counts.

Summary and Discussion

Samples of blood from two peripheral sites, the ear lobe and the thumb pulp, were taken in the course of routine examinations of workmen. They were compared in respect of total white cell count, differential count, R.B.C. count, and haemoglobin estimation. The total white cell and differential counts showed no statistically significant difference for the two sites. The red cell count showed that while the readings for the two sites, when considered for each case individually, did not differ more than was expected from experimental causes ; the ear samples were consistently a little higher. The haemoglobin estimations showed a similar but insignificant tendency.

The difference, however, is so small that there appears to be no reason to forgo the practical advantages associated with using the ear lobe as a source of blood in industrial medical practice.

We are indebted to Professor R. E. Lane, who suggested this investigation, for his advice throughout. Our thanks are due to Mr. S. Taylor and Mr. K. W. Boyle who made the blood counts.

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Raynaud's Phenomenon*

ANDREW MEIKLEJOHN

Medical terms, no matter how precise in their derivation, often lack the descriptive, human quality of our common speech, as illustrated by painters' colic, hatters' shakes, potters' asthma, knife-grinders' rot, brass-founders' ague, and many others. In recent years among workmen operating vibratory tools, pneumatic hammers and chisels, there has been increasing mention of " white fingers ", " dead fingers ", and " dead hand ". The condition, " Raynaud's phenomenon ", its causation, incidence, and clinical course among selected occupational groups in Great Britain was comprehensively investigated by Agate (1949), Agate and Druett (1946), Agate and Tombleson (1946), and more recently by Jepson (1954). While it was recognized that the disorder was not uncommon in the general population, the findings suggested that in certain workmen the disease was an effect of their occupation, in fact an industrial disease.

Affected workmen in these groups, however, were unable *simpliciter* to recover compensation as the disease was not included in the list of " prescribed diseases ". On March 21, 1950, following the judgments in several test cases in the Court of Appeal and the House of Lords and the rejection of a claim in 1949 by the Industrial Injuries Commissioner and two Deputy Commissioners, the " Minister of National Insurance referred to the Industrial Injuries Advisory Council for consideration and advice the question whether Raynaud's phenomenon should be prescribed under the National Insurance (Industrial Injuries) Act, 1946 ".

Under the Industrial Injuries Act, 1946, and as extended, financial benefits, formerly workmen's compensation, including in certain cases supplementary allowances, are provided for injuries caused by accident arising out of and in the course of employment and likewise for certain diseases designated " prescribed diseases ". Even so, in some instances, as a result of judgments in the courts, workmen have obtained compensation for diseases which are not prescribed on the interpretation by the courts that the disease was due to accident in which the injury had resulted from the cumulative effects of recurrent minimal trauma, in effect a series of repeated similar minor accidents. Ultimately, however, the courts rejected this concept of industrial disease by repeated accident and regarded it as a continuous process. This had the effect of excluding such cases from compensation. The only remedy then open to affected workmen was to press to have their condition included in the schedule of " prescribed diseases ". Experience over many years has proved (Meiklejohn, 1954) that this is no simple process as the conditions of prescription have been very rigidly defined successively in the reports of the Samuel Commission (Departmental Committee on Compensation for Industrial Diseases, 1907), the Rolleston Committee (Home Office, 1933), and the Dale Committee (Ministry of National Insurance, 1948).

Furthermore, workmen have an urge, indeed the very human one, to obtain prescription of their diseases, as industrial injury benefits are substantially higher than sickness benefits under the National Insurance Act. In recent years this attitude has been excellently illustrated by dermatitis; workmen recognize one variety only, namely, occupational dermatitis. Likewise in dusty occupations there is one cause of breathlessness, dust, so that progressively over the last 20 years the definition of the disease has widened from silicosis in particular to pneumoconiosis in general. Now the agitation is to embrace bronchitis and emphysema.

As previously stated, the Minister of National Insurance on March 21, 1950, referred Raynaud's phenomenon to the Industrial Injuries Advisory Council. They in turn passed the question for consideration to the Industrial Diseases Sub-Committee, who, after full investigation, submitted a majority and a minority report (H.M.S.O. Cmd. 9347). The Council by a majority adopted the Sub-Committee's Majority Report (the conclusion of which is that Raynaud's phenomenon should not be prescribed). Dr. L. G. Norman was unable to support either the majority or minority report of the sub-committee and submitted a dissenting note :—

> " In my opinion Raynaud's phenomenon caused by the use of vibratory tools should be a prescribed disease with the limitation that a claimant should not qualify for disablement benefit unless his loss of faculty exceeded 10 per cent."

From the reports of the sub-committee it is clear that the members investigated the subject very thoroughly and that, while unable to present a unanimous report, they were agreed upon certain fundamental points. Thus the majority report records quite unequivocally that :—

> " The survey has confirmed that there are to be found a certain number of clearly occupational cases of Raynaud's phenomenon caused by the use of vibrating hand and machine tools and involving a definite although relatively minor degree of disablement."

Later in discussing the degree of disablement in these occupational cases it is recorded that generally it is very trivial, often amounting to no more than temporary inconvenience, and that under the Industrial Injuries Act the great majority of cases might well be assessed at less than 1%. A small group of cases existed in which the disablement was greater but even in these the sub-committee considered that the disablement might probably be assessed about 3%. It would appear that this trivial degree of disablement—loss of faculty—was the basic reason for the recommendation that Raynaud's phenomenon should not be added to the schedule of " prescribed diseases ".

Nowhere, however, do the sub-committee mention whether or not they had observed a single case in which

*A Report of the Industrial Injuries Advisory Council. (Pp. 16. 6d.) Ministry of Pensions and National Insurance (1954). Cmd. 9347. H.M.S.O. London.

the disablement arising out of the disease was substantial. By inference Dr. L. G. Norman's dissenting note suggests that he foresaw the possibility of occasional cases in which the loss of faculty might exceed 10% and indeed this was the substance of the argument presented by Mr. C. R. Dale in his sole Minority Report.

The fact stands that the sub-committee and ultimately the Council unanimously accepted that, among certain workmen, Raynaud's phenomenon occurs as an occupational disease. Disagreement among the members was on the question of prescription. Rejection—by a majority—was based almost entirely on the trivial degree of disablement in the great majority of cases, but there is no doubt they were also in some measure influenced in their decision by the long-familiar stock arguments—and which will persist—about the difficulties of diagnosis in the individual case, the fear of an avalanche of frivolous claims, and the range of industrial cover. The Council's recommendation has the effect that the odd workman who may be substantially handicapped by Raynaud's phenomenon caused by his occupation is denied the remedy and appropriate benefits under the National Insurance (Industrial Injuries) Act, and this despite the fact that he and his employer pay weekly contributions to the insurance fund.

The sub-committee realized that their conclusion would give rise to disappointment and apparently they themselves had some misgiving, for the chairman in the report to the Minister stated on behalf of the members that their decision was presented " on the understanding that you would be informed of their desire to be given an opportunity of reconsidering the question if as a result of any future developments it should appear to you that they could usefully do so ".

To some it might seem that Dr. L. G. Norman's note had provided a workable scheme, which, having regard to the facts and if adopted, would at least have given the workman the appearance of justice. The Byssinosis Scheme and Benefit Schemes for pneumoconiosis have long provided evidence of the difficulties of such arbitrary limitations. In practice Dr. Norman's scheme would probably have resulted in the certification of the great majority, if not all, of diagnosed cases. This follows from the fact that in the assessment of the degree of disablement the doctors would be largely dependent on the patient's description of his intermittent attacks, and, in reference to this and entirely without cynicism, it has been my long experience and shared by others that patients have an uncanny power of learning and repeating the convincing story. Furthermore, in workmen's compensation it is generally accepted that where there is reasonable doubt decisions should be liberal in favour of the injured workman ; that is to say that the workman should be given the benefit of the doubt. So to reject any diagnosed case as less than 11% would not reflect much liberality. Some will argue that the assessor must be satisfied that reasonable doubt exists ; some doctors are more easily satisfied than others and this leads to lack of uniformity of decisions in different areas throughout the country.

The Industrial Injuries Advisory Council's single term of reference was to advise the Minister whether Raynaud's phenomenon should be made a " prescribed disease ". To decide this they were bound to observe, as they did, the principles established for the prescription of industrial diseases. This being so, existing knowledge of the disease and previous experience of the arguments advanced to include (or exclude) other diseases in the list of " prescribed diseases " immediately foreshadowed the ultimate decision and indeed the division of the members of the Council. And so it will continue due to no fault or lack of humanity in this most excellent body.

Raynaud's phenomenon is not to be prescribed. But that is not the end ; the general problem remains. Are we to go through the same prolonged labour—four and a half years in the present instance—and inevitable stillbirth in relation to bronchitis, emphysema, " rheumatism ", impairment of hearing, and anxiety states in particular occupational groups ? Furthermore, in industrial diseases the emphasis so far has been on causation of the disease by the occupation, while increasingly workmen are raising the issue of aggravation of existing diseases. Sooner or later this issue also must be faced.

There is another very important fact which cannot be avoided, namely that the Industrial Injuries Act introduced the principle of insurance into workmen's compensation. The workman, by a special weekly contribution, insures himself against the risks of industrial accident and disease. This consideration, of course, was outside the Council's terms of reference. The government having introduced the insurance principle—*pace* Sir John Cameron, Q.C.—must accept the implication, which means that any workman who contracts an industrial disease is entitled to expect that he will receive of right the appropriate injury and disablement benefits and supplementary allowances. It is entirely irrelevant to adduce arguments about the small number of cases, the slight degree of disablement in the majority of cases, and the difficulties of diagnosis and administration. To the injured workman his case is the single and total issue and an issue of just rights.

While not germane to the present issue of Raynaud's phenomenon, it is necessary to allude to the substantial differences which exist between benefits under the National Insurance Act and under the Industrial Injuries Act. As figures are sometimes more impressive than words let us take the example of a young married man with two dependent children. He contracts acute pneumonia whereby he is gravely ill and away from work for six weeks. Under the National Insurance Act he receives the following weekly payments (scale at January, 1955) : self 32s. 6d., wife 21s. 6d., first child 10s. 6d., second child 2s. 6d.—a total of 67s. If this same workman is incapacitated, yet in sound health, for a similar period by a septic thumb following an injury at work these are the corresponding weekly payments : self 55s., wife 21s. 6d., first child 10s. 6d., second child 2s. 6d.—a total of 89s. 6d. The difference in the benefits is substantial, the explanation, of course, being the insurance against injury.

Legislation for workmen's compensation despite anomalies and defects has a long and honourable record

in the social history of Great Britain. In its development guiding principles have become established but the question now arises whether these are still effective to meet the demands and outlook of the new system of comprehensive social insurance introduced in July, 1948. Current medical knowledge of the influence of occupations and working environment on the health of workmen can no longer support, without modification, the hitherto arbitrary division, as represented by " prescribed diseases ", between social and industrial diseases, especially as these attract different rates of benefit. Doctors find themselves increasingly mystified by the legal and administrative interpretation of disease. That they should be required to assess loss of faculty in percentages by stages of 1% is quite unrealistic. Is there any fundamental reason under comprehensive social insurance why sickness and injury benefits—based on subsistence level—should not be the same during the first 156 days of incapacity—that is, the statutory period of injury benefit? If such uniformity were established many medical problems would be resolved and valuable savings in medical and administrative man-power and costs would be achieved.

Among the arguments hitherto advanced in support of higher rates of benefits for industrial accidents and diseases as opposed to those of non-industrial origin are the following. First it is essential that men should enter dangerous trades vital to the community. This need merits special provision for casualties. Employers and workmen have recognized this so that danger money and dirty money have been included in the negotiation of wage rates. Secondly a workman disabled at work suffers his injury while working under a contract of service, a factor which does not attach to non-industrial accidents and diseases. This argument, however, does not take full cognizance of the fact that many workmen by their own negligence or that of their fellow workers contribute—often substantially—to their own injury at work. By the passing of the Law Reform (Contributory Negligence) Act, 1945, contributory negligence lost much of its power as a defence—especially in jury actions. Furthermore, the Law Reform (Personal Injuries) Act, 1948, abolished the doctrine of common employment as from July 5, 1948. Thirdly it was thought that additional injury benefits would help to diminish the number of actions at Common Law. This has not proved to be true—indeed they have increased substantially and have aggravated the law's delays. One reason for this is that receipt of injury benefit does not exclude, in addition, remedy at Common Law, if negligence by the employer is alleged. Furthermore, the legal aid scheme for poor persons has enabled some workmen to promote such claims while safeguarding them against legal costs. In any case trade unions generally include legal aid among the benefits to members, but without involving the union in the payment of costs if awarded against the workman.

The immediate need—so it seems to me—is for the Minister of Pensions and National Insurance to inquire comprehensively into the working of the Industrial Injuries Act in relation to the National Insurance and associated welfare Acts and incidental Acts referred to above. It may be that the existing system and principles must continue. Even so, the record of an up-to-date exposition of the subjects and viewpoints would be invaluable.

Since 1953 a distinguished committee, officially known as the Departmental Committee to Review the Diseases Provisions of the Industrial Injuries Act, under the chairmanship of F. W. Beney, Q.C., an acknowledged authority on workmen's compensation, has been taking evidence. The report so far has not been published. It is to be hoped that this committee will elucidate, if not resolve, many of the outstanding problems or, if this is not possible, direct the attention of the Minister to the need for a commission with wide terms of reference.

The Report on Raynaud's phenomenon must not be shelved. It must be an important landmark in the history of the development of industrial injuries insurance and " prescribed diseases ".

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British Occupational Hygiene Society

First Ordinary Scientific Meeting

The first ordinary scientific meeting for the presentation of original papers was held on January 10, 1955, at the London School of Hygiene and Tropical Medicine, by the kind permission of the Dean.

About 70 members of the Society and their guests were present.

Abstracts of the communications, which were well discussed, are given below.

Summer Comfort Zones for Workers in Light Industries *

D. HICKISH (London School of Hygiene and Tropical Medicine) said that workers in factories and a postal sorting office were questioned about their thermal sensations and the replies assessed according to a scale of standard sensations. Measurements of the thermal environment were made concurrently. The investigation was confined to those doing light or sedentary work during the summer.

Discontinuities in the linear relationships between the thermal sensation, described on a numerical scale, and the thermal indices of the environment are shown to occur under conditions which suggest the onset of sweating beneath the clothing. The comfort zones are determined in terms of these critical conditions, and also in terms of the temperatures at which more than 20% of people questioned experienced thermal discomfort. The zones determined by the two methods are for practical purposes identical.

The importance of clothing in requirements for thermal comfort is illustrated by the cooler conditions required by postal workers wearing uniform. Male and female factory workers were found to require thermal conditions not significantly different, this being attributed to their selection of appropriate clothing.

COMPARISON OF THE THERMAL REQUIREMENTS OF FACTORY WORKERS IN WINTER AND SUMMER

Thermal Index	Winter		Summer	
	Optimal Condition	Upper Limit	Optimal Condition	Upper Limit
Air temperature °F ..	64·7	72	66·8	75
Globe temperature °F ..	65·1	74	68·5	75
Effective temperature °F	60·8	66	62·9	70
Corrected effective temperature °F	61·7	68	64·4	71
Equivalent temperature °F	62·3	70	65·9	73
Dry kata cooling power (100° F)	6·06	4·5	6·3	4·5

* This is an abstract of a paper which has been accepted for publication in the *Bulletin of Hygiene*.

†This is an abstract of a paper that has been accepted for publication in this journal.

Energy Expended on Some Industrial Processes†

D. TURNER (Environmental Hygiene Research Unit, Medical Research Council) said that the energy expended in the performance of 48 industrial processes was assessed by measurement of the metabolic rate during work, and by a subjective assessment made by the observer. Comparison of the results obtained by these two methods showed a close agreement. It is suggested that for purposes of giving guidance to medical officers when suggesting suitable employment for unfit or elderly persons satisfactory results would be provided by subjective assessment.

"Fluon" (Polytetrafluorethylene): A Preliminary Note on Some Clinical and Environmental Observations

P. J. R. CHALLEN, R. J. SHERWOOD, and JOAN BEDFORD said that C_4F_4 polymer was manufactured in this country under the trade name "fluon" and in the U.S.A. as "teflon". It is supplied to numerous firms who fabricate, by a process of sintering and machining, electrical components, self-lubricating bearings, and parts for chemical plant. This note reports conditions found in a fabricating works. Processes investigated were the sintering (carried out by pressing the polymer and heating to 350 to 380° C.) and the machining of the resulting product.

Clinical phenomena in employees exposed to fume from the processing of "fluon" were first recorded by Harris (1951). After exposure to the fume there is a latent period of a few hours and then a feeling of general malaise, aching muscles, a sense of oppression behind the mid-chest, a dry throat, and a cough followed by shivering and profuse sweating; but there are no abnormal signs apart from a high temperature and pulse rate. The symptoms abate after 24 hours, with no after-effects. Seven cases are described which include the four employees regularly working in the "fluon" section of the works. Two cases were seen during the acute phase: *x*-ray examination of the chest revealed no abnormality. One case had marked conjunctival congestion.

A skin irritation was complained of by two employees working on a "dispersion process". This process is similar to paint spraying. It uses "teflon" dispersed in 10% chromic acid.

Atmospheric concentrations of fluorine compounds were determined by drawing samples of the air through a filter-paper followed by a bubbler to separate solids from gases. Early investigations found concentrations of up to 3·5 mg./cu.m. (expressed as "fluon") in the workshop; following improvements in the ventilation and building layout, this has been reduced to about 0·3 mg./cu.m.

Microscopical examination of air samples showed the presence of a fine, highly refractive fume, with a few large particles—apparently partially disintegrated to a fume.

Despite the tenfold reduction in air conditions, cases of fever still occur occasionally. It would appear that the habit of smoking can lead to the inhalation of fume from "fluon" particles contaminating the tobacco.

Improved exhaust ventilation is to be installed, a no-smoking rule is to be strictly enforced, and the temperature controls on the ovens are to be checked.

Since this communication was presented, a sample of urine has been obtained from a worker during a fever attack. This has been found to contain 5 mg./l. fluorine.

REFERENCE

Harris, D. K. (1951). *Lancet*, **2**, 1008.

Interlaboratory Trials on the Quantitative Determination of Quartz in Samples of Respirable Size

G. NAGELSCHMIDT (Safety in Mines Research Establishment, Sheffield) reported that under the auspices of the Medical Research Council a panel of analysts had compared a number of chemical and two physical methods for the quantitative determination of quartz in mixtures containing other silicates. A reproducibility of results of the order of 5% for quartz percentages above 50% and fair reproducibility for smaller amounts of quartz in mixtures was found for chemical and *x*-ray diffraction techniques.

Representation of Respirable Dust Concentrations

W. H. WALTON (Central Research Establishment, National Coal Board, Isleworth) said that the present practice of representing the respirable content of dust clouds by the fraction of particles smaller than 5 microns in diameter was unsound and would give misleading results because respirability is not a unique function of size, but depends on the aerodynamic properties characterized by the free-falling speed of the particles. It has the practical disadvantage that the so-called respirable dust cannot be isolated for estimation by mass or surface area or for chemical analyses. A new criterion of respirability, based on the free-falling speed of the particles, is proposed, which closely resembles the lung retention characteristics and which can be matched by practical selective sampling methods.

The Observation of Dust in Mines

W. B. LAWRIE (Factory Department, Ministry of Labour and National Service) showed a sound film of dust from a range of tools, and under different kinds of dust control systems. It included dry and wet rock drills and the Holman dryductor, dry and wet auger drilling, dry and wet use of pneumatic pick, and scraper hauling and the blowing out of holes.

In another sound film Mr. Lawrie demonstrated high-velocity, low-volume local exhaust ventilation systems to control dust from a hand-grinder and a pneumatic chisel.

THE JANUARY (1955) ISSUE

The January (1955) issue contains the following papers :—

Research in Industrial Health in the Chemical Industry. By M. W. Goldblatt.

Manganese Poisoning in Moroccan Miners. By J. Rodier.

Dermatoses in Jute Workers. By John Kinnear, John Rogers, Owen A. Finn, and Alexander Mair.

Talcosis of Unusually Rapid Development. By G. P. Alivisatos, A. E. Pontikakis, and B. Terzis.

Injury to the Respiratory Tract by Isocyanates Used in Making Lacquers. By Åke Swensson, Carl-Eric Holmquist, and Karl-David Lundgren.

Dimethyl Sulphate Poisoning. By T. R. Littler and R. B. McConnell.

Vanadium Poisoning from Gas Turbines. By R. C. Browne.

The Toxicity of Ozone in the Presence of Oxides of Nitrogen. By W. M. Diggle and J. C. Gage.

The Construction of Critical Orifices Working with Small Pressure Differences and Their Use in Controlling Airflow. By H. A. Druett.

Miscellanea :

The Health Hazards of the Senior Executive. By A. R. Cooper.

The Health of the Industrial Worker in Iraq. By A. Michael Critchley.

Book Reviews.

Abstracts.

A number of copies are still available and may be obtained from the Publishing Manager, British Medical Association, Tavistock Square, W.C.1, price 12s. 6d.

OBITUARY

CECIL GORDON ROBERTS

Cecil Gordon Roberts, formerly Deputy Treasury Medical Adviser, died suddenly on September 8, 1954, at the age of 48, at Tamworth, Australia, while spending a short holiday with his wife.

Dr. Roberts spent his early childhood near Liverpool ; he was educated at Uppingham College, at Cambridge, and at the Westminster Hospital, London. At Cambridge he took a Natural Science Tripos, Part II, in physiology and for the rest of his life he remained interested in physiological problems. He became a resident medical officer at the Westminster Hospital and, later, resident physician at Ruthin Castle. He was offered a registrar's job at Westminster Hospital, but after getting married he joined the Medical Branch of the General Post Office in 1934, under Sir Henry Bashford, who was then Chief Medical Officer, and served there from then onwards until 1953. He was promoted Second Medical Officer in 1943 and Chief Medical Officer in 1945. When the Treasury Medical Adviser's office and the Medical Branch of the General Post Office were merged into the Treasury Medical Service in 1948, he became Deputy Treasury Medical Adviser, retaining charge of the medical affairs of the Post Office. In 1953, he was attracted by the possibility of organizing and building up an important medical service in Australia, and he applied for the post of Director of the Division of Industrial Hygiene, New South Wales Department of Public Health, Sydney, Australia. With such wide experience and personal qualities, his friends were not surprised that he was selected for the post.

Through his family he was connected with merchant adventure, as his father traded with South America ; one of his ancestors was founder of Emmanuel College, Cambridge, and one of his less distant relatives was a high civil servant in the Treasury in the nineteenth century. Of all those connexions, rooted so deeply in British tradition, Dr. Roberts was very conscious and proud.

He was very keen on history and the study of evolution, both in the field of natural and social conditions. He was a cheerful man, full of optimism and vitality, much interested in every new aspect of his own subject as well as in the general progress of mankind. During the war years that high spiritedness combined with his energy, drive, and hard work, contributed to a great extent to carrying out the difficult task of the service he was working for. He enjoyed travel, good food, and good company, and he was a most charming conversationalist. He was a born speaker but behind the ease and elegance of his oratory there was a sincerity and seriousness of purpose in trying to improve social conditions in general and especially the fortunes of the people under his care. The freshness of his approach and his underlying scientific attitude became an important support in the development of industrial medicine in this country in the last decade.

His death means a great loss, not only to his friends and collaborators, but also to his branch of medicine, and to the former Post Office Medical Service in particular. He leaves a widow and two sons.

W. E. CHIESMAN

BOOKS RECEIVED

(Review in a later issue is not precluded by notice here of books recently received.)

Annual Report 1953–4 of the British Standards Institution. (Pp. 200. 5*s*.) London : British Standards Institution. 1954.

The Chemical Pathology of Animal Pigments : Biochemical Society Symposia No. 12. (Pp. 84 ; illustrated. 12*s*. 6*d*.) London : Cambridge University Press. 1954.

Epilepsy. By Letitia Fairfield. (Pp. 159. 8*s*. 6*d*.) London : Gerald Duckworth. 1954.

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The Human Use of Human Beings. By Norbert Wiener. (Pp. xii + 199. 18*s*.) London : Eyre and Spottiswoode. 1955.

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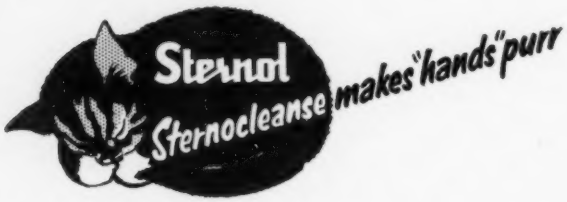

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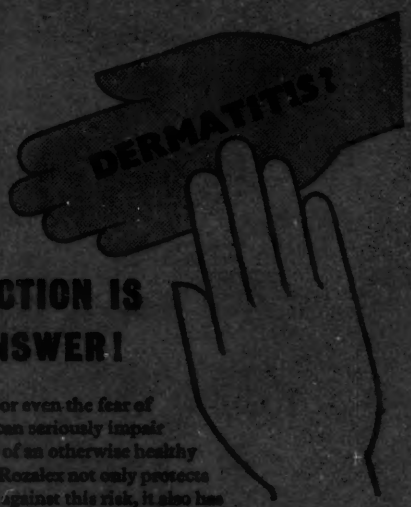

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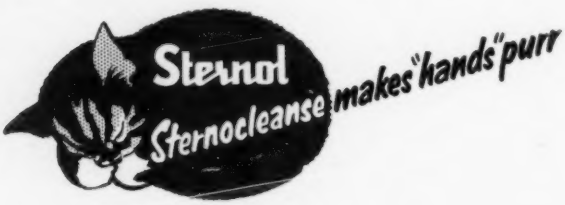

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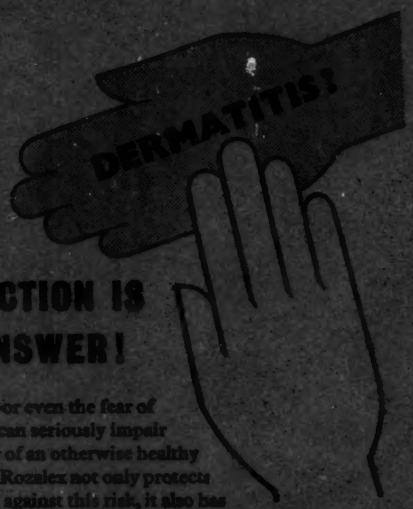

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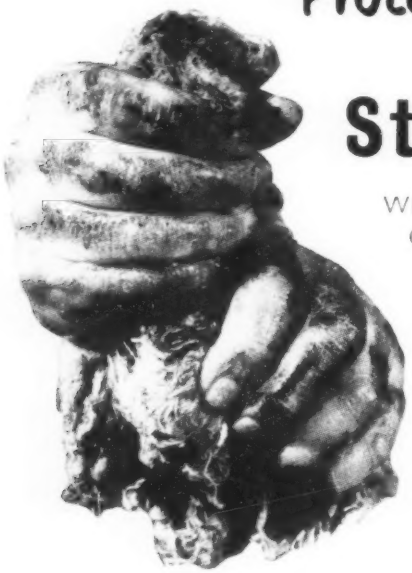

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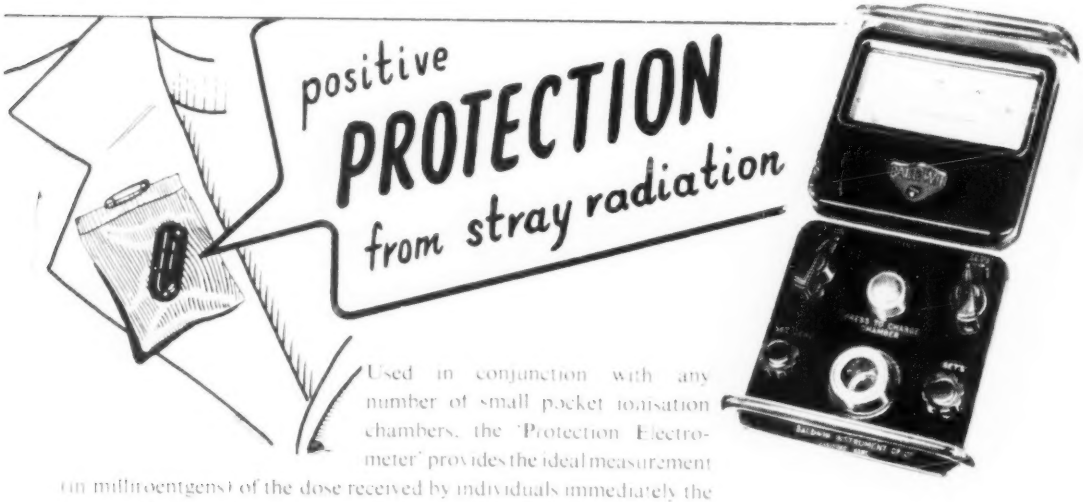

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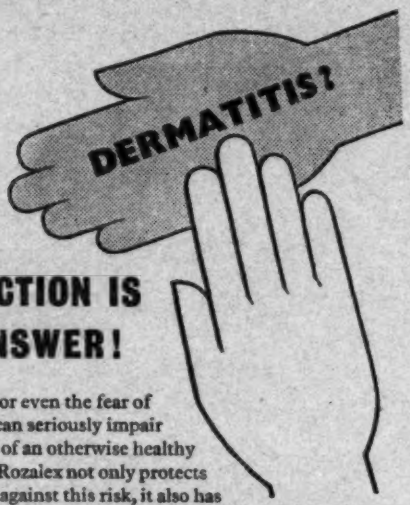

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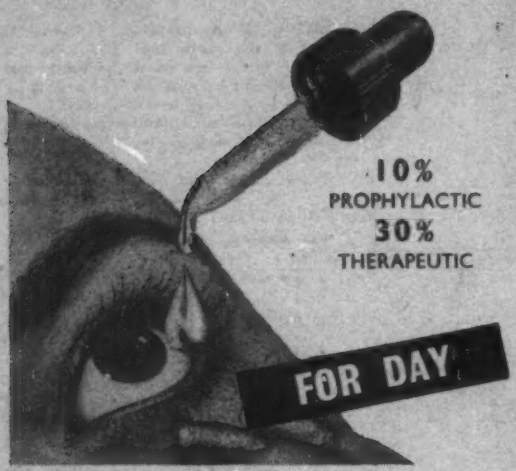

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